PRACTICAL ACOUSTICS
AND PLANNING AGAINST NOISE

by

HOPE BAGENAL

A.R.I.B.A.

PART AUTHOR OF 'PLANNING FOR GOOD ACOUSTICS'
LECTURER IN ACOUSTICS AT THE ARCHITECTURAL
ASSOCIATION SCHOOL

METHUEN & CO. LTD. LONDON

36 Essex Street Strand W.C.2

First published in 1942

PRINTED IN GREAT BRITAIN

INSCRIBED TO THE MEMORY OF

P. W. BARNETT

I find your letters in the green-backed files
Signed long ago, and half expect to see
You with your pipe revolving caustically
Facts of acoustics, gels, and flooring tiles.
And find my memories answered in the smiles
Of men that knew and loved your company
And in a spirit of warmth kindling me—
As this warm autumn sun the sense beguiles.
And catch beyond the woods an emerging spire;
There you lie buried still within our view,
Joined to our labours as the roots to trees
Or to diffusing light magmatic fire,
And seem to catch a comment fallen from you
Upon the mystery of processes.

H. B.

GARSTON,
8 *November* 1941

PREFACE

THIS BOOK sums up briefly the major facts of building acoustics as we find them to-day, and is intended for the use of students and also for builders and architects with practical problems before them. The aim has been to provide a short handbook, useful during an interim period when libraries and works of reference are fewer and less accessible than formerly. For this reason scientific material has been selected rather than collected, and some theoretical aspects which would need a full discussion have not been touched upon. The section on theatre design gives some practical results differing from those in Chapter VI of *Planning for Good Acoustics* and must be taken to supersede them. Throughout the book the needs of post-war planning have been kept in mind.

I am indebted first to Mr. Fitzmaurice and Mr. Allen of the Building Research Station for permission to draw largely upon their book, *Sound Transmission in Building*, and, with the permission of H.M. Stationery Office, to reproduce a number of their very useful illustrations. I am indebted to the Noise Abatement League for valuable material on planning against noise and for permission to extract from their leaflets; also I must thank Sir Christopher Robinson, secretary to the League, for help with my paragraphs on noise nuisance. I owe to Mr. Edward Carter, editor of the *Journal of the Royal Institute of British Architects*, permission to reproduce the notes on concert-hall platforms and various illustrations from that journal. I must thank Miss M. E. Lloyd for her useful work on Bed-sitting Room flats. Finally, in respect of the discussion upon frequency curves and distributed absorption, I owe much, directly and indirectly, to Dr. Alex. Wood and to Mr. J. McLaren of the B.B.C.

H. B.

4 September 1941

CONTENTS

ILLUSTRATIONS

INTRODUCTION

ACOUSTICS FIRST influences planning and second presents technical data, materials, details. On the technical side, like other modern subjects, it is always developing, changing; and theories, once rigidly held, are liable in a few years to be altered. But there is still a precipitation of real knowledge; and as new buildings test themselves over years it is possible, by honestly comparing theory with practical results, to build up the kind of body of information that architects need.

Our subject is therefore experimental, but an experiment in the art of building is not the same as a scientific experiment. A scientific experiment isolates facts of the same species to discover specific properties: in building we have to relate dissimilar kinds of facts to discover their social uses. This is only to say that our subject has a humane reference first and a scientific reference second. We need laboratory results, but those results are only one of the factors to be weighed. We must see them in their context and keep the broad purpose of our enquiries always in view. The scientists will not do this for us;[1] we must do it for ourselves. Moreover, applied science is not autonomous like pure science. This is often lost sight of in the many interesting fields for 'research' opened up by technical studies, and the modern promiscuous use of the term 'research' is evidence of a confused attitude. But modern building touches human life at a hundred other points besides the scientific. It is much more a new craftsmanship than a new science. A

[1] 'Officially', says a recent writer in *Nature*, 'physicists know nothing about "life".'

craftsmanship has always included art, ethics, technical and economic activities. A new craftsmanship must add something of the awareness and alertness found among modern scientists. A craftsmanship can contribute to the quality of the civilization it serves. Autonomous science may destroy all civilization. A craft is rational rather than logical. We shall find in our subject instances in which the logic of one set of facts alone has not led to results generally useful, but has had to be related to the logic of another set of facts. An example is worth noting. Concentration upon microphone technique and upon a limited theory of sound absorption led to unsatisfactory types of music recording studio. Improvement followed upon a more adequate relationship which admitted the artistic preconceptions of the human ear, together with a theory of absorption which included resonance-absorption: and this has had the effect of making music studios more like concert rooms. But to get at the *adequate relationship* needs discrimination in values. Therefore the co-operation of educated architect and engineer, with a sense of perspective, is vital in technical studies. Experience must be laid beside experiment.

Again, in the field of sound insulation craftsmanship is required for practical reasons. Very careful work by the various trades is necessary, because the unseen labours must be done as efficiently as the seen. That means the building operative must become a craftsman. But he will not be encouraged in this on the rush job where the main object is to get on and get out. Therefore a social and economic factor must be recognized. A great cause of noise is the cheap mechanical equipment produced in response to bad economics which have enlisted good brains. The remedy is not only to ask for more knowledge from the scientist, but also to ask for a fair price for good work and for a skill in the workman.

Sometimes an architect is rewarded in a particular way by a job. The client has seen the need for a fair price, the foreman and crowd of young semi-trained workmen have caught an interest in the problems set, and in some new processes carefully explained. Someone has said to them 'Take your time and do a job that will last.' Then knowledge has its effect, but also there is found as the work proceeds

a spirit, a quality. What has happened is that the human factor has dominated the scientific and economic: and the result is a building with some indefinable quality, a home for human activities, a home for the mind.

PLANNING AND SEGREGATION

Modern buildings must protect against noise as well as against rain and cold. This will modify planning in the direction of the grouping of units, and the segregation of noise sources. Structural insulation, after years of investigation, has yielded many secrets, but remains technically difficult and expensive. It is cheaper on unconfined sites to conquer noise by segregation and separation. Intelligent planning can always reduce the extent of noise problems. Fitzmaurice and Allen, in the opening paragraph of *Sound Transmission in Buildings*,[1] say: 'It is very much open to question whether it would be possible to contrive structural insulation adequate to compensate for serious deficiencies in planning and in any event considerable additional cost would be entailed.'

First in importance come residential buildings because they involve living conditions. If a block of workmen's dwellings should solve on paper all the most rigorous economic problems, but make sleep impossible, it would be useless. This could easily happen. Hospitals, schools, colleges, hotels, come next in importance: and we must note the new type of technical college where noisy trades are now taught in machine shops adjacent to classrooms and lecture rooms. Then council chambers, committee rooms; then business buildings where business is done on the telephone and where employees need some defence against noise if efficient work is to be done; then assembly halls, theatres, music rooms. Also, looking ahead, we must envisage more of a type such as the community centre and village college where many separate activities go on at the same time, and must be defended the one from the other. Add to these the frequency to-day of temporary structures for schools, camps and

[1] Fitzmaurice, R., and Allen, W., *Sound Transmission in Buildings*, Practical Notes for Architects and Builders. D.S.I.R. publication. H.M. Stationery Office. 1939.

hospitals, all of which can be planned for less rather than more noise.

In the R.I.B.A. *Alternative Problems in Design* there are subjects which can be taken by students as special acoustic subjects, but all subjects ought to be planned to avoid noise communication through structure, through adjoining doors and opposite windows, just as measures are taken to provide adequate lighting. Thus it is bad planning to put, for instance, library or committee rooms under a games room on an unconfined site and encounter the expense and uncertainty of structural sound-proofing, when it could be avoided.

ZONING REGULATIONS

In recent Town and Country Planning legislation the principle has been recognized that noxious trades and industries ought to be segregated, and it is usual in any Planning Scheme to group them in a 'Special Industrial Zone.' But most of the 'Special Industries' specified as noxious in the Ministry of Health's Model Clauses for Schemes are smoke and smell producing, not noise producing. Noise ought to be recognized as causing serious nuisance under circumstances liable to arise. In trades where sheet metal is ground, punched, or sawn ; in joinery works using planing and moulding machines and circular saws ; in power stations giving out a high-pitched brush scream, the noise may carry long distances. A case in North London occurred recently in which a block of flats standing immediately on the boundary between a residential and industrial zone became seriously impaired as to living conditions owing to factory noises just over the boundary. If the flats had been 100 yards back from the boundary the complaints would not have occurred. This specially concerns night workers who have to sleep for a part of the day.

But there exists a clause in the 1932 Act by which *a Planning Authority is empowered to confine any industry to the Special Industrial Zone* which it thinks might be harmful to the residential or commercial parts of a town. Noise producing trades and occupations ought therefore to be dealt with under that clause. But a greater awareness of the danger of noise nuisance is desirable. The conversion of

a works to electric driving power does not mean that it will be quieter.

Power stations ought to be confined to the industrial zone and kept some way back from the boundary. They are active all night. Yet they are often found near residential property.

Milk distributing centres work all night and have heavy traffic coming and going both by road and rail. The road traffic noise can be considerably reduced by means of pneumatic tyres, rubber kerbs to the interiors of lorries, rubber fittings to churns, or conversely rubber gangway mats on the unloading quays; but complete silencing is impossible. The unloading quays ought not to come near residential property.

Dirt Tracks can be, and ought to be, controlled under a planning scheme (see clause 28 of Ministry of Health Model Clauses for use in the preparation of schemes). Dirt tracks provide evening programmes in which motor bicycles, having removed their silencers for the sake of greater power, contend for the palm amid pistol shots, revolving rattles and loud-speakers. A decision in the High Court, Chancery Division, in 1934 in respect of a dirt track, complained of by neighbours, resulted in restrictions which prohibited speedway meetings for a large part of the year.[1] Civic planning against noise in the early stages can prevent that kind of deadlock. Town planners have already noted that *Commercial Areas* are less noisy than Industrial and that recreational belts can be interposed. But school playgrounds must be noted as unavoidable sources of noise: recreational areas are not necessarily quiet.

Civil Airports. Extensive exercise of zoning powers in respect of residential buildings ought to accompany the decision on the siting of a new airport in order that houses shall not be built near it. How near houses can be allowed must depend partly on the prevailing wind. Aeroplanes make unavoidable noise taking off into the wind, and if this takes them over houses at a low height noise complaints will

[1] Law Report, December 12, 1934. *The Times*, December 13, 1934. The judge said 'he was satisfied the noise made by the machines had occasioned an actionable nuisance to the plaintiffs. . . . The noise must be stopped.'

occur. This applies equally to schools, colleges, hospitals, nursing homes. Therefore the placing of a non-residential belt round an airport and especially towards the prevailing wind is necessary.[1]

SITE SELECTION AND NOISE

Traffic is much noisier on a hill and at cross roads where gear changing is frequent. Examples are the principal thoroughfares of the cities of Winchester, Norwich and St. Albans. Many motor vehicles comply with noise regulations on top gear but are very noisy on low gears. Motor buses are noisy at points adjoining stopping places, where they change gear. This means that some sites are unsuited for some buildings. Council chambers, school classrooms, law courts, ought not to be planned on the noisy front. Committee rooms in town halls and county halls always suffer from being planned convertible into assembly rooms and placed on main front. A laboratory may be rendered useless if microscopes, galvanometers and other sensitive instruments, cannot be read owing to vibration. Sometimes heavy night traffic finds a shorter route through a quiet residential area and destroys amenities. Therefore local authorities must bear in mind that traffic regulations in one area may have serious results on adjoining areas.

The night worker who must try to sleep by day needs consideration,[2] in hostels, in nurses' homes, in working-class flats, and a range of comparatively quiet rooms screened from traffic ought to be envisaged.

For the above reasons, therefore, if it is a question of a choice of sites, architects and surveyors will do well to warn their clients of the dangers and disabilities arising from noise and vibration.

PLANNING OF FLATS

The noise sources in order of nuisance in flats are wireless sets, dogs barking, slamming of doors, footsteps overhead, intermittent traffic, refuse bins, vacuum cleaners, lifts and

[1] See also Noise Abatement League Leaflet, No. 11.
[2] See below p. 18.

staircases, plumbing, boiler room noises. Noise insulation is fundamental to the design and is not merely incidental. Nowadays we must think of flat plus wireless set.[1]

Blocks are best planned L-shaped or extended, and not on enclosed courts which serve as noise containers. Three-sided blocks or Z-shaped blocks can give varied aspects so that bedrooms can be planned on the quiet side. *A vital principle is to plan bedroom against bedroom on the party partition*, and not bedroom against the living-room with its wireless set. This is an example of how planning can halve the risk. Flats can be dissociated by staircases or by baffle lobbies between pairs. The closer and more cell-like, and the cheaper and thinner the structure, the more persistent become the internal noises. This is unavoidable. Regard tiled kitchen, bathroom, W.C., living-room, as noise sources and plan them in column, each over each. The too ingenious plan which sandwiches a bedroom between living-rooms above and below, or brings a W.C. over a living-room, is asking for trouble. Equally important is the providing ample space for shafts to take the services, as noted above.

Also it must be noted that, where ordinary commercial structural flooring is provided, close carpeting in the terms of the lease is essential to prevent vertical transmission of impact noises. The parquet floor ought to be ruled out.

Since efficient structural sound-proofing involves floating floors and double partitions it is obvious that strength of structure calculated to carry only 4-in. floors and 2-in. single partitions is insufficient. In other words, efficient sound-proofing means stronger structure and some small extra in

[1] Flats in my opinion come first in respect of noise insulation because they present, as a class, the extreme ease in which speculative building produces bad housing although controlled by bye-laws. Flats are generally built to sell first and to house afterwards. Hence cheap noisy equipment, thin taut structure, lifts put in by one firm and maintained by another, boiler room equipment not insulated in the basement, and above all the rush job in which none of the trades have time to do their work properly ; in short, the whole well-known circus of speculative building. Noise is the result of these things and an analysis of noise complaints points to them. The 'circus' must be humanized. The method of attack is for all to contribute something—land owner, building owner, contractors, professional man, tenant. But professional man specially because he exists to serve the public first.

total height to allow for floor thicknesses. The thicker the partitions the less will they vibrate to the shutting of distant doors. (For the principles of complete sound-proofing of flats see Chapter II.)

CONTROL OF AMPLIFICATION BY MANAGEMENT

The extreme cases of noise nuisance occur when a wireless fan is seeking foreign stations with a powerful set at night in a living-room adjoining a bedroom where another tenant is trying to sleep. In tenants' agreements a pious clause binding a tenant not to use his wireless 'unreasonably' is in practice found to be quite useless.[1] But such cases cannot occur when the amplification is restricted by the Management, or when all loudspeakers are turned off at a central switch at 11 o'clock. Also in cases where loudspeakers are owned by the Management, restriction of loudness could be adapted to the insulating efficiency of floors and party partitions: builder and wireless engineer could then work together.

MEANING OF 'THRESHOLD NOISE'

'Threshold' is, roughly speaking, the familiar noise of ordinary affairs in a room, to which we grow accustomed and which masks the intruding noises which we might consider a nuisance. Noise is one thing, noise nuisance is another (see p. 15). Ordinary threshold noise in residential buildings ought to be not more than from 20 to 30 phons, under ideal conditions, but this is obviously on the low side: the mother of a large family can often lead a healthy and happy life in an environment of 50 to 70 phons, while rich secluded persons, and those a prey to nervous fears, will complain of 30 to 40. We need only note here that a phon represents the minimum increase of sound which the human ear can detect.[2] Hence annoyance caused in a room by a particular intruding noise through a wall or floor depends on the level of noise already existing in the room itself. *But on a quiet site a tenant may be disturbed by a much less noise, and there-*

[1] See below p. 16.
[2] For definition of units of sound see below p. 63.

fore on the quiet site the party wall requires to be proportionally more efficient. Roughly speaking, a living-room is a place where a higher 'threshold' exists than in a bedroom. In a living-room, for instance, one can turn on one's own loudspeaker and thereby entirely cut out the loudspeakers of others. Some persons can even work with their loud-speaker going. In a bedroom, on the other hand, the average person requires a certain degree of quiet in order to get to sleep and stay asleep. Hence the reason of the importance, already insisted upon, of not planning bedroom against living-room on the party wall. Sleep means health: we rebuild ourselves and recover our courage, our *élan vital*, during sleep, and where sleep is impaired the health of urban populations suffers slowly but surely.

BED-SITTING ROOM FLATS

Blocks of flats of this kind, giving proper living conditions at small rents to students, hospital nurses, school teachers, etc., are urgently needed but present some difficulties. Each bedroom is also a living-room, and neighbours' wireless sets, on both sides, may prevent sleep. Also bathrooms are often a source of noise in the late and early hours. Also, in summer, noise comes through open adjoining windows. The principles to go upon are best illustrated in reference to a plan of Miss M. E. Lloyd's, illustrated in Fig. 1. Miss Lloyd has made a special study of the type both practically by living therein, and also theoretically. The points can be summarized as follows:

1. Cupboards as baffles between bed-sitting rooms.
2. Windows shielded from each other by recessing to avoid the free passage of sound through adjoining windows.
3. Bathroom baffled by a shaft from adjoining flat.
4. Bed separated from corridor noises by own bathroom.
5. Floors to be close carpeted in the lease.
6. Quiet refuse disposal by means as follows: Kitchen next corridor with dustbin cupboard cleared daily in fibre bins removed on rubber-wheeled trolley.

Miss Lloyd urges that the living-room portion be not less than 17 ft. by 16 ft. and bedroom portion not less than 6 ft. by 12 ft. The baffle cupboards must reach the ceiling. The lifts to be in separate brick shafts disconnected if possible from structural floors, and both staircases and lifts trapped by lobbies and doors from corridor. The corridor to be, preferably, an open access balcony, not enclosed, but must in any case have a solid, not a board and batten floor.

It must be noted in the case of large blocks that the *star-shaped plan* giving acute angles between the various arms brings windows of the inner rooms closely opposite each

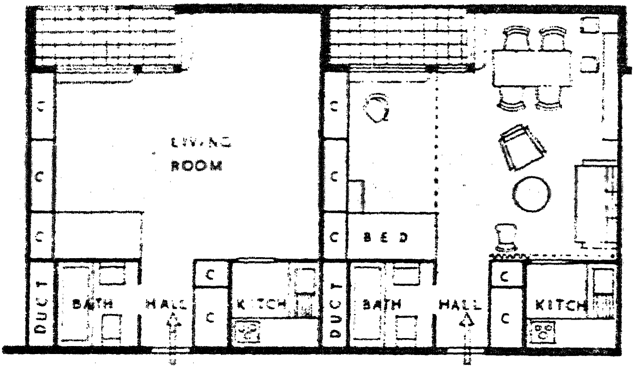


Fig. 1.—**Miss M. E. Lloyd's Plan for quiet Bed-sitting Room Flats.**

other with corresponding noise and lack of privacy: also that traffic noises collected by the arms are noticeably intensified at these inner windows.

Doors. All the trouble taken about insulating partitions will be useless if thin, badly-fitting doors with noisy latches come next each other. Doors of one-room flats must be spaced at a maximum equal distance from each other, or if in pairs then recessed and each with a little separate lobby. Next to loudspeakers and lifts, the shutting and snapping of hall doors is often the most complained-of noise: they must stop against a good rubber button and must have quiet latches. This is a really important item. *Noisy ball catches* on doors of cupboards, bathrooms, etc., are also a prime nuisance.

LIFTS AND MECHANICAL EQUIPMENT IN FLATS

Also the proper planning of lifts and equipment may save serious complaints. Even good quiet lifts tend to run noisy at times, and if there are thin party partitions all down the shaft, loud noises may be transmitted. If lift motor, and control board, are at the bottom of the shaft noise risk is considerably less but expense is more. If motor is at top of shaft then it must not be bolted to structure but must be on a true floating bed. This bed consists of a concrete block, on some insulating material, and must be large and heavy enough to control machine ' dance ' and vibrations, and that in turn means that more head-room must be provided for lift machinery. Control boards often make an air-borne noise like rifle fire, and have also a knock travelling through structure : they ought to be recessed off, and stand unbolted on a thick coir fibre mat. These points are known to engineers, but are often ruled out owing to expense by promoters and designers, and hence trouble. For the problem of lifts in working-class flats see below, p. 14.

Noise always accompanies cheapness in case of equipment as well as in case of structure. There are, for instance, excellent silent lift doors on the market. The cheap slam gate is a prime cause of complaint. Lift shafts with staircases ought to be planned so as to be thoroughly well trapped off from hall doors and from party partitions by means of double doors and a baffle lobby. Planning of machines can also greatly diminish structure-borne noise from basement. Noisy pumps, fans, accelerators, air compressors, refrigerators occurring in frame buildings, must not be fixed at stanchions or bolted to continuous floors, so as to be wholly at one with the human beings above. And it is useless expensively insulating the main machines, and then bolting their pipes, trunks, cables to the nearest stanchion or beam. If insulation is embarked upon it must be followed through—and *separate structure must be aimed at.* The corks, felts, etc., when used as sleeves, or linings to hangars, close to a powerful vibrating source, are palliative not remedial ; they become compacted and will only cut out a fraction of the transmitted vibrations. For electrical equipment noises see below, p. 55.

SOCIO-ACOUSTICS OF WORKING-CLASS FLATS

In England, as in other countries, working-class families with few children can adapt themselves to flat life where nearness to work and other inducements exist. *The job of the designer is to see that living conditions are not in fact impaired.* There are two vital problems—the child and the night worker. The flat ought to be a home.[1] Therefore babies and young children must be envisaged and they need to sleep for an hour or two by day and not cause too much noise to neighbours at ordinary times. And in the same flat, often, there is the night worker, a lodger, trying to sleep. Yet the noise problem must be seen in its stringent relationships. Where low rents depend on cheap building, extra expense must eventually take away from proper expenditure on food. Yet better quality homes for workers would pay for themselves after a term of years.

The menace of bed bugs makes it imperative to have structure which will not move slightly and cause cracks in finishing materials.[2] Therefore partitions ought to weigh at least 40 lb. per square foot. An advantage in the ordinary four-floor block without lifts is that brick party walls, and also brick partition walls, can be carried up from foundations and solid structure ensured.

In *the planning of working-class flats* it is equally important not to put living-room against bedroom on the party wall. Avoid small courts and wells which act as noise containers. Also the type of three bedroom or 'maisonette' plan which gives two floors to a flat is thoroughly dangerous for the reasons given above, p. 7. Also the principal bed-

[1] Vacuee experience seems to reinforce the argument against flats. London working people with children, who come out of flats, express a deep longing for the houses with backyards they once occupied.

[2] Note on bugs. The theory of bugs is not generally understood. Since bugs nourish themselves only on human blood it is useless to recommend materials such as glass, silk, etc., which 'bugs will not eat.' The only relevant consideration is the possibility of cracks opening in structures and finishes which will provide harbourage for bugs. In such cracks they will remain unfed and quiescent for months waiting for the incoming tenant. Therefore any light partition liable to crack, or any joint at skirtings, is as dangerous as the presence of accessible soft materials used for sound-proofing. And if such materials are properly sealed off they are not in themselves sources of attraction, and will not necessarily increase the danger.

rooms ought to be planned away from access balconies. The type of partition illustrated in the Ministry of Health report is given in Fig. 1*a* (see also p. 40).

Floors. The most difficult noise problem in working-class flats is that of floors, owing to impact noises. The Departmental Committee of the Ministry of Health in their *Final Report on Construction of Flats for the Working Classes*, 1937, recommend a standard minimum of defence for party walls between flats of 'an 8½-in. wall plastered both sides (about

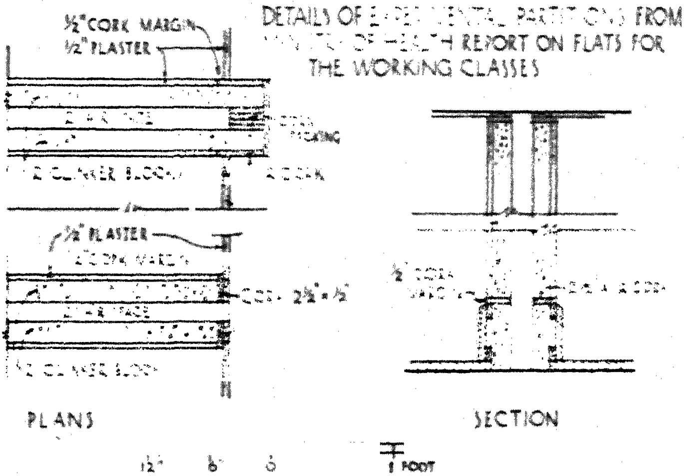


Fig. 1*a*.—Partitions for Working-class Flats.

50 phons) or its equivalent'. For floors the Report does not make *recommendations*, owing to the technical difficulties of the subject, but it makes some *suggestions*. Apart from 'flanking effects'[1] the floor which might be regarded as a standard 'is one which gives, for blows corresponding to heavy footfalls, a degree of quietness about 15 to 20 phons superior to a bare concrete floor': and a gain of 25 to 30 phons 'is very acceptable' and can be obtained with a 'floating floor finish in conjunction with an insulated ceiling'. The floors suggested as suitable for working-class flats are noted below,

[1] See below, p. 34.

p. 44. In my own opinion since cheap structural floors are almost useless against footsteps, even a gain of 8 to 10 phons is worth while. An extra thickness of structural floor will not of itself increase efficiency against noise except indirectly in so far as it increases rigidity and weight of total structure. It is often found in practice that owing to thin floors it is not possible to carry the sound-proofing elements. The problem is acute, because in workmen's flats the close carpeting of rooms, as part of the tenant's agreement, is not always desirable. But some cushioning finish to a floor is a help, but it must be reasonably hygienic. A thick linoleum laid in a mastic on the cement screeding or rubber latex cement flooring, is hygienic and is less noisy against small impacts than a magnesite type composition floor or a wood block floor. Some recent practical tests have shown that the problem can be tackled by allocating some extra cost for a floating floor under living-room and principal bedroom in each flat. An extra four inches in the total thickness dimension of the floor for first, second, third and fourth floors is then necessary, and will slightly increase the total cube of the building.

For examples of floor design, see below, Chapter II.

Lifts in working-class flats are controversial, yet are likely to increase in localities where tenants can educate their children in their use. A lift can serve as many as sixty flats and still be an amenity of real value. To quote from 'Housing Manager' writing in the *Phœnix* for December 1937:

'The inspection and maintenance service, with certain safety devices, renders the lifts as safe as it is humanly possible to make them. Their misuse is not dangerous to life or limb, but merely wasteful of current. Every tenant who wishes for one is given a latch key which will only open the outer lift door when the lift is at that floor, to which it has been summoned by a push button. It is self-operative in the usual automatic way. Children under sixteen are not allowed the use of this key, and it is liable to be forfeited if found in their possession; they are, of course, allowed to enter with their parents. At first, with the ingenuity and resource which is, apparently, born into London children, they found their way in unfailingly by fair means or foul. . . . After a month or two this particular game was, however, more or less abandoned. . . .

'The legitimate use of the lifts by the lame, the old, those with

weak hearts, and those who are short of breath, as well as by tired mothers coping with a baby and a heavy shopping bag, entirely justifies, we consider, their installation, where it can be done at an additional cost of not more than 4d. to 6d. a week per flat. To achieve this, or an even lower cost, is a matter of construction planning, and would appear to involve the use of continuous approach balconies so that a sufficient number of flats may be served by the same lift.'

I have quoted these highly practical paragraphs because they give data to a designer. But equally important is the following paragraph :

'We have found it advisable to turn off the current at 9 o'clock in the evening, by which time even the latest Saturday evening shopper should have returned, and also on Sunday afternoon, so that the banging of the lift doors shall not disturb the rest of the adjoining tenants.'

This latter precaution is valuable owing to the inevitable noise made by cheap lift equipment : see also paragraph on lifts above, p. 11.

Quiet door stops to hall doors in working-class flats, the avoiding of ball catches to cupboard doors on party partitions, and quiet electric switches, are quite as important for working-class as for middle-class flats on account of the sleeping by day of night workers. And for exactly the same reason, quiet vacuum cleaners and fibre refuse bins are greatly to be preferred.

NOISE NUISANCE AND THE WORK OF THE NOISE ABATEMENT LEAGUE

A legal definition of actionable noise nuisance was given by Justice Luxmoore in Vanderpant *v.* Mayfair Hotel Co., Ltd. in 1930, as follows :

'Apart from any right which may have been acquired against him by contract, grant, or prescription, every person is entitled as against his neighbour to the comfortable and healthful enjoyment of the premises occupied by him, and in coming to a decision whether his right has been interfered with and a nuisance thereby caused, it is necessary to determine whether the act complained of is an inconvenience materially interfering with the ordinary physical comfort of human existence, not merely according to elegant and dainty modes and habits of living but according to plain and sober and simple notions obtaining among English

people. (See Walter v. Selfe, 1851.) It is also necessary to take into account the circumstances and character of the locality in which the complainant is living. The making or causing of such a noise as materially interferes with the comfort of a neighbour when judged by the standard to which I have just referred constitutes an actionable nuisance, and it is no answer to say that the best-known means have been taken to reduce or prevent the noise complained of, or that the cause of the nuisance is the exercise of a business or trade in a proper manner.' [1]

In producing evidence as to interference with comfort the occurrence should be first noted of loss of sleep. Also acoustic experts are agreed that if noise is irregular and intermittent, such as the barking of dogs, it is difficult to get used to it, and it is therefore more likely to interfere with comfort. A minor but useful point is the proper hearing of telephone conversation: since telephone loudness is designed for comfortable conditions inability to hear on the telephone is evidence of intrusive noise above a permissible level. The courts have granted injunctions restraining the ringing of church bells, the noise from an hotel kitchen, singing, holding noisy entertainments and bringing together disorderly crowds, using a steam organ in connection with a merry-go-round, making an excessive noise in carrying on a trade, and testing aeroplanes in a residential neighbourhood. See also the restrictions imposed upon the management of a dirt track quoted above, page 5. The Court will not interfere with building operations conducted in a reasonable manner, but noisy operations such as pile driving have been restricted to the hours of day.[2]

In regard to loudspeakers and gramophones the Home Office has prepared a model bye-law dealing with nuisance caused by these instruments. In districts where this bye-law has been adopted the police can take action on the complaint of three persons. It is found in blocks of flats that the ordinary clause in the tenant's agreement that the tenant 'shall cause no unreasonable noise' is difficult to uphold in the courts, if complaints should be made because of the lack of well-defined standards. But if the management wish to ensure real quiet in respect of dogs, wireless or gramo-

[1] See Strauss, H. G., 'The Law and Noise' in *Silencing a Noisy World.* Published by the Noise Abatement League. 1935.
[2] Strauss, H. G., *ibid.*

phones, it can be done by a tenant's agreement having a clause whereby the use of wireless or gramophone is prohibited except under written licence of the lessor. In practice this means that the licence is granted to new tenants, but can be taken away again if they make a nuisance of themselves in the opinion of the lessor. The agreement ought also to insist on the close carpeting of the whole of the flat. In London it has been found that tenants who desire quiet will sign such agreements.

Noise and the efficiency of workers has been the object of tests by various scientists. They are well summed up in Dr. Davis's book *Noise.*[1] Experiments by Weston and Adams[2] on groups of weavers wearing 'ear defenders' showed that this defence increased by about 1 per cent the average output of work per hour per weaver. Dr. Davis says: 'A most interesting and suggestive fact which emerged from the work was that the detrimental effect of noise was greatest during the hours at the beginning of periods of work and also high at the end when the subjects were becoming fatigued, but not so appreciable during the middle. Indeed it was found that even after years of work in a noisy environment the worker goes through the process of adaptation daily. He does not become completely acclimatized to the noise at all, and the adaptation wears off when fatigue approaches.' Pollock and Bartlett[3] found that the interference due to noise upon workers increased with the difficulty of the task and the amount of concentration needed. My own view is that it is in educational work of all kinds in cities that noise causes inefficiency. The process of learning, of relating the new fact to the known fact, is really a contemplative process, and the effect of intrusive, irregular noise is that of a series of subconscious calls to action, each separately to be resisted if concentration is to be maintained. Also the teacher knows well the added fatigue of raising his voice at a critical point in a presentation in order to drown out the passing motor bicycle or gear-changing 'bus.

[1] Davis, A. H., *Noise*, p. 13 *et seq.* Watts & Co.

[2] 'Two Studies in the Psychological Effects of Noise.' 1. By K. G. Pollock and F. C. Bartlett. 2. By H. C. Weston and S. Adams. Industrial Health Research Board. H.M. Stationery Office. 1932.

[3] Industrial Health Research Board, *op. cit.*

But it was owing to their conviction that *noise was steadily contributing to ill-health* that caused Lord Horder and some other humane physicians and citizens to initiate the Noise Abatement League in 1933 in order to combat the evil at its source.[1] 'Doctors are definitely convinced,' says Lord Horder, 'that noise wears down the human nervous system, so that both the natural resistance to disease and the natural recovery from disease are lowered.' (*Quiet*, July 1937.) To protect health by securing adequate sleep, to promote the idea of quiet as a desirable thing and combat avoidable noise, were the objects of the League, and some excellent work was done. The League put forward in 1934 amendments to the Road Traffic Bill then before Parliament, which were carried. It promoted the 'no hooting' order at night in built-up areas, and took part in the Ministry of Transport's Departmental Committee to investigate the reduction of noise in motor cars. It has also contributed to the efforts towards strengthening the law against the unreasonable use of loudspeakers and gramophones, and just before the war its technical committee was investigating the problem of road drills. A useful piece of propaganda was the recommendation for the use of rubber wheels to milk carts and the use of rubber kerbs to pails, bins and hospital equipment. In many ways the League has performed a public service by focussing opinion upon the noise problem.

THE NIGHTWORKER

The League also envisaged the plight of the *night worker who must sleep by day*. A useful recommendation among others was that sleeping loggias should be provided on the roofs of hospitals, relatively protected from street noises, for night nurses.

[1] The League was in fact one of those public defence societies, like the Pedestrians' Association, the Society for the Protection of Ancient Buildings, the National Trust and others, which have been called into being in recent years by the need for the more humane and educated portion of the community (in all classes) to protect itself against anti-social forces. These societies proceed upon the principle that all citizens have equal rights in the amenities of their surroundings.

Since in war-time the night worker is more important than ever we here give the *League's recommendations for the protection of night* workers.

'Rooms overlooking the street are all more or less subjected to the same degree of traffic noise. Height above the pavement has little or no effect on the diminution of the loudness. But rooms in the roof space with dormer windows set well back behind a shielding parapet or projecting cornice can be much quieter. Bedrooms should preferably be located overlooking the garden or quiet area defended by the building itself from the intrusion of street noise. Bedrooms under cornices and projecting balconies tend to be noisy.

'Sleep is more disturbed by sudden intermittent noises than by the general hum of ordinary daily activities. The noise of slamming doors and the clatter of household utensils are specially disturbing.

'Many find relief by the use of ear-plugs or ear stops, which may be purchased from reputable dealers.

'The hanging of doors is important, and fitting with rubber or felt increases sound insulation and helps to eliminate disturbing sound. Pneumatic door closers are also useful. The reduction of noise from this source will be found to be most effective, as corridors and landings are usually sparsely furnished and reverberant in character, thus increasing sound and making the noise of slamming doors very penetrating.

'Household utensils such as pails, pans, metal water-jugs, etc., can be silenced by the use of rubber gaskets, edge covers, shoes and handles which are now obtainable. This is specially important and effective in the silencing of refuse-bins which are often placed on hard paving.

'Papier-mâché bowls for washing up, fibre refuse bins and rubber floor-covering may also contribute to the elimination of the disturbing clatter usually associated with ordinary household domestic activities.

'Care should be taken to select and use only those vacuum-cleaners, sewing-machines, electric-washers, etc., of the silenced type.

'In the matter of furnishing, it must be remembered that the general effect of carpets, curtains and absorbent furniture coverings is to reduce the loudness of intrusive noise and to deaden noise originating within the room itself.

'The modern tendency to do away with carpets and to cut down the furnishings to the bare essentials in simple, modern labour-saving furniture, introduces reverberant "bathroom" conditions under which the maintenance of comfortable quiet is almost an impossibility. The light sleeper obliged to take his rest during the activities of the day should therefore be accommodated preferably in a well-furnished room containing acoustic absorbents such as carpets and curtains.'

PRIVATE HOUSES

The new building estates after the war will consist largely of small houses in groups, and there must be at least a minimum of defence against noise. In such houses, or in the semi-detached kind, the main problem is the neighbour's piano or loudspeaker at the other side of the party wall; and in summer, noise coming through open adjoining windows. There are three defensive measures, contributory, and all worth carrying out.

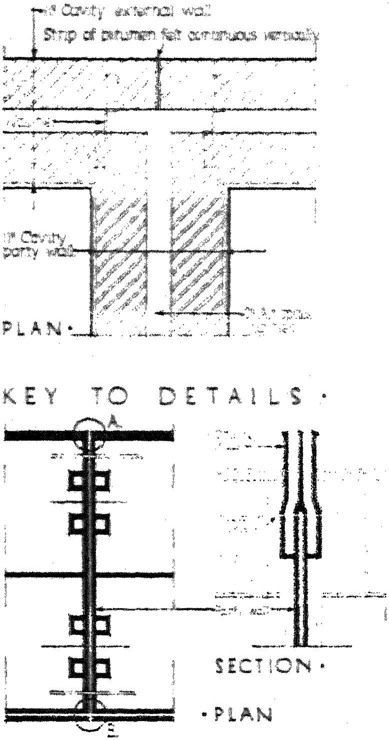
First, separate structure at the party wall. It has been shown in speculative house-building that a two-leaf party wall, without wall ties, and stiffened by the fireplace jambs. can be both effective and reasonable in cost. By this means an increase in noise reduction of some 10 phons over a single party wall can be provided which is well worth while.[1] The leaves ought to be a narrower 4½-in. brick leaf truly separated by at least 2 in. from a 9-in. brick leaf. Separation of concrete foundations is desirable but not essential, and the two leaves must be united to form the stack under the roof just above an insulation course of asbestos cloth (see Fig. 2). If one of the leaves has no fireplace, then buttressing can be by partitions, as in Fig. 3.

Second, the front and back external walls must be considered with the party walls, and here the problem is to *stiffen* adequately without the use of wall ties, so that there shall be a real separation of structure between the brickwork of adjoining houses. The method of stiffening is obviously to design breaks or bays which in fact act as small buttresses between which the windows extend. This is illustrated as a sketch in Fig. 3, and is obviously capable of variation. The principle to follow is that of lateral buttress walls giving

[1] The enterprising firm of builders of the Parkfield Estate, Swindon, have built experimental houses similar, but with party walls, in one case 9 in. single thickness, and in the other of two leaves, one 3½ in. separated by a 2-in. air space from a 9-in. leaf. The construction was concrete blocks without wall ties, and the leaves in both cases were stiffened by the fireplace jambs, and were united at a level within the roof space by an asbestos insulating layer. These were tested by B.R.S., and the increase in insulation of the double party wall over the 9-in. single party wall was 10 phons for air-borne, 11 phons for impact noises.

different planes between which standard window panels could be fixed.

Third, project forward one lateral wall in each house bay to give a screen as between open windows in adjoining



By permission of H.M. Stationery Office.

Fig. 2.—Semi-detached Houses. Sound Insulation at Party Wall. (From Fitzmaurice and Allen.)

houses, as illustrated in the sketch or, alternatively, recess alternate bays in a row of house fronts as in the same figure. By these means some real reduction of loudspeaker noises in summer might be provided together with some extra privacy. It is to be noted that some of the modern staggered

3

plans for housing, such as Miss Denby's 'All Europe House' (*R.I.B.A Journal*, June 26, 1939), do in fact provide some screening between windows. Casement windows of adjoining houses ought not to open towards each other, but open in parallel.

In respect of planning Mr. F. L. Barrow has pointed out to me that there is a type of plan for semi-detached houses which in fact gives relatively less transmission through party

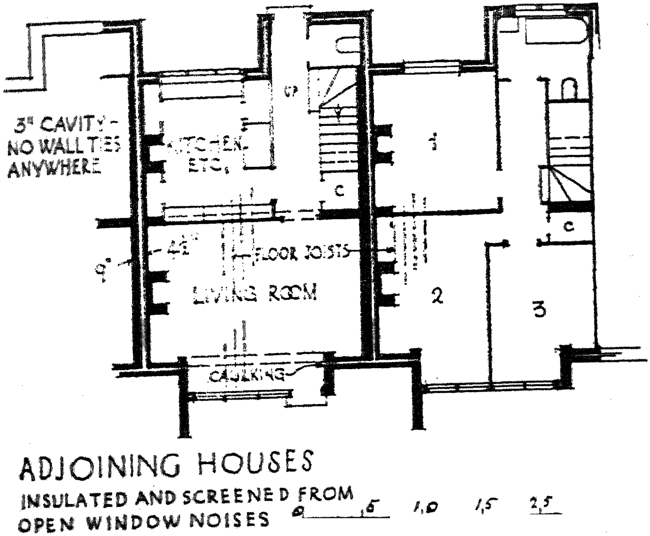


Fig. 3.—Sound Insulation of Houses in Rows.

wall, namely that in which hall, staircase and kitchen come against the party wall on ground floor, and likewise staircase, bathroom and small bedroom on first floor. Thus reception rooms and main bedrooms are not in direct contact with the party wall. This principle could be more widely applied.

Other important points are to plaster the party wall, including the strip at floor level corresponding to joist thickness, and also not to run floor joists into party wall but parallel to it, and supported on a spine wall or beam. Finally, if cheap plumbing units are to serve pairs of houses, they

must be designed in shafts so as not to weaken party wall insulation, and this applies also to communal heating (see p. 53).

In detached country honses servants' quarters ought to be insulated owing to their wireless set. Also guests' rooms with telephones must not broadcast conversation all over the house, and must therefore be baffled by a lobby and have adequate floor insulation, or close carpeting. This also applies to the nursery. Shallow joist floors, though they may be structurally safe, bend under furniture loads and tauten the ceiling beneath, giving noisy conditions (11-in. joists are desirable). Bathrooms and W.C.'s must be planned over each other and not come over living-rooms, because wood ceilings loaded with partitions tend to transmit.

The type of residential building consisting of converted *maisonettes* or new house with separate flat on second floor often gives serious noise complaints. The living-room ought to be planned above living-room, or above [illegible] and not above bedroom. Insulation of the wood floors is highly desirable. For this see p. 40 below. For a quiet nursery floor finish, see p. 47.

HOSPITALS

In modern hospitals, owing to mechanical equipment and for other reasons, noise insulation has become a fundamental planning problem and is no longer incidental. A new problem has entered the modern hospital with the paying patient accommodated in the single bed ward. He is more exacting, not only because he must pay, but also because he is alone in the room and has plenty of opportunity to listen for transmitted noise. Also if paying patients are permitted loudspeakers, their rooms become themselves sources of noise. There is now a tendency to locate main kitchen on top floor to avoid expensive air extraction. But it is of first importance not to locate paying patients' rooms under the main kitchen floor because the main kitchen has a number of machines difficult to insulate structurally and the tiled floor causes high transmission of impact noises. It may be found useful to group the boiler-house containing oil burners, air compressors, accelerator pumps, in a part of the building having main kitchen and electrical treatment rooms above;

and to build that part in a more massive brick structure, allowing ward block wings to be of lighter frame construction.

Labour wards are also sources of noise and must be planned in small groups with a special lobby so that they are trapped from main corridor, and they require double partitions, without wall ties, between wards. Also the nurseries connected with labour wards must not occur opposite paying patients' rooms. The position of sluice rooms and ward kitchens, both of which are sources of noise, can greatly affect the amount of noise penetrating to beds. These ought not to give directly on to wards, but must not be far away. A hospital main corridor is itself a source of noise and if fanlights open on to the main corridor from single bed wards complaints will be caused; therefore the requirements of cross-ventilation for which the fanlight was designed must be weighed against noise nuisance. If loudspeakers are allowed in single bed wards there is an added reason for omitting fanlights to corridors.

In addition the position of bedrooms for night nurses who must sleep by day must be considered. These must be grouped and defended by baffle lobbies from ordinary corridor noises. Also they must be defended against loudspeakers or gramophones in adjoining day nurses' or sisters' rooms.[1] In the general planning of wards in hospitals on noisy sites the quiet side ought to be allocated if possible to surgical wards because ultra hygienic conditions are needed for surgical wards, whereas medical wards are now permitted some of the more hygienic kinds of sound-absorbing ceiling such as the 'sanacoustic' type tile.

Floor finishes in hospitals can add to noise or reduce it, especially in main corridors. Board and batten floors are very noisy underfoot and must be avoided (see also p. 47). In addition loose latches to doors can be very noisy, and doors on main corridors ought to have closers or door stops.

Noises in ward kitchens can be greatly reduced by placing sheet rubber on draining boards, tiled sills, and on floor areas where trays are stacked. This principle applies equally to sluice rooms and in both sluice room and ward kitchen

[1] See also a suggestion of the Noise Abatement League, p. 18 above.

a sound-absorbing ceiling, formed of one of the hygienic absorbing tiles is of great use in reducing clatter.

Hut Hospitals. Since these are mainly on ground floor acute problems do not arise, but yet planning can halve the noise risk. Service yard, boiler-house, pantries with potato washers, transformer room, are sources of noise and must be segregated from wards. Single bed wards, for officers, must not come next ward kitchens, and sluice rooms require the same short distance removal from wards as in the case of permanent hospitals above noted.

A chief source of noise in all hut hospitals is the long extent of corridor flooring which, if constructed of boards and battens, will magnify impact noises. Instead use thick lino on concrete, or wood-block, or asphalt, for corridors.

Rooms used by M.O.s for *medical boards* and rooms in clinics where patients are interviewed need to be defended against noise and must not have fanlights opening on to noisy corridors. These rooms require a hygienic sound-absorbent in the ceiling, both in the case of hut hospitals and permanent hospitals.

HOTELS

The first need in hotels is to protect against heavy traffic noise, since they must often be noisily situated. This involves closed windows and air-conditioning. But in any case plan best bedrooms on the quiet side. Since hotels illustrate problems of acoustics and ventilation in an extreme form, it may be well to summarize them at this point. It is of first importance to provide large ducts and slow air speeds in order to avoid noises of air-surge. This applies first to the main inlet shaft, and is specially important where the air enters at the top of a high building to avoid dust and smoke and goes downward in a shaft penetrating bedroom floors. Shaft walls of 9-in. brickwork are desirable. Also branch ducts in builders' work are less noisy than metal ducts. In the method of air-conditioning in which air crosses a room diagonally, hung ceilings are desirable to conceal the trunks, and these ceilings if hung on felt-insulated hangers give some measure of floor sound-proofing. If air is extracted upwards into main plumbing

shafts, then plumbing noise, due to the chute of water down a tall building, is liable to be a real nuisance; it tends to escape into bedrooms through extract grilles unless absorbing baffles are placed behind grilles. In the method of air-conditioning in which air is introduced at ceiling level and extracted on same side a greater air velocity through inlets is required and precautions must be taken in the shape of directing vanes in mouths of ducts, and gratings having rounded edges. But baffled trunks mean more powerful fans and plenty of headroom for large fans must be provided by the architect. The larger and slower a fan the less air-surge and the less noise from rotating parts. Air-conditioning equipment with its pumps and washers is more easily insulated on basement floors where anti-vibration beds can efficiently dissociate rotating parts from structure. On upper floors the efficient structural insulation is much more difficult (see also paragraph on fan and trunk noises below, p. 52). Acceleration pumps, air compressors, refrigerators, pneumatic communication equipment, knife grinders, potato washers, bakery machinery, must be specified as silent and *not put on party walls*.

When an hotel building has been effectively protected from traffic noises the comparative quiet of bedrooms will make telephone conversations, snores, bathroom and plumbing noises, footsteps in corridors and the cleaning of corridors, more easily heard. Under such conditions double partitions each 2½ in. thick, insulated at margins and not bridged by wall ties, are necessary between bedrooms, or, alternatively, heavy single partitions at least 40 lb. per sq. ft. The single 2-in. partition with thin plaster coat will not insulate against snores. This applies with equal force to all hotel buildings and all flat buildings on quiet sites where there is no masking noise from familiar traffic. The same structural defence is necessary between bathroom and bathroom and between bathroom and plumbing shaft. Corridors must not be board and batten floored but have rubber or carpet gangways on the solid; cork skirtings will guard against small impact noises while cleaning.

In residential hotels on quiet sites where bedrooms may become bed-sitting rooms in which wireless sets and gramophones are found, the rooms require a baffle of cupboards,

as in bed-sitting room flats (see above) or else the equivalent of a 4½-in. wall between room and room. Even then some control of amplification by the management is desirable.

In all hotels lift shafts must be planned with a baffle of linen rooms between the lifts and bedrooms. Pantries with tile floors and communication bells can be very noisy and a lobby between them and the corridor is necessary. In large hotels, ballrooms and masonic lodge rooms which are hired out independently must be planned so as not to disturb bedrooms. A ballroom on an internal court must have solid roofing structure of rigid, double steel lay lights not penetrated by ventilation openings; the ballroom will then need separate ventilation. Lodge rooms ought not to have windows on small internal courts. For details of quiet equipment for hotels the student should consult the Noise Abatement League Leaflet No. 6, *Hotels*.

SCHOOLS

These ought to have cloakrooms, lavatories, common rooms, gymnasium, on the noisy side; and classrooms away from traffic. Schools also have sources of interior noise which vitally influence planning. The gymnasium, the handicraft rooms, the hall and school stage or theatrical workshop, the domestic-science school, are sources of noise. Among teaching rooms the art room and geography room where there is coming and going on a hard floor, are comparatively noisy and ought not to come over classrooms. The head master's room ought to be baffled by a lobby from the noisy vestibule or concourse. Corridors are liable to be very noisy and require a wood-block, or linoleum or cork laid on the solid, and quiet floors to classrooms are highly desirable. Classrooms and lecture rooms need a sound-absorbent treatment in the ceiling and this is difficult to arrange if panel heating in the ceiling is specified. The acute cases of discomfort occur when highly reverberant conditions known as 'bathroom conditions' coincide with traffic noise. (For acoustic design and treatment of school halls see page 103.) Doors planned opposite each other will transmit noise which would be cut off by doors far apart. Special baffle doors ought to be used more freely to cut off noisy

quarters. Movable partitions used to divide classrooms ought to be as heavy as possible and close tight.

In *schools of music* the lecture rooms and administration need to be segregated and defended from noise, and also the music library and rooms used for examination. It is not possible to compose in musical examinations, or read scores, if strains of music filter in from outside. Also a clear distinction needs to be drawn between 'practice rooms' and 'teaching rooms'. They ought not to adjoin. Practice rooms ought to be segregated and removed some distance, or placed on a noisy front, but need not be expensively insulated the one from the other because a student practising drowns out his neighbour's sounds. But teaching rooms, though often used for practising, *need quiet for personal tuition*, and must be carefully insulated the one from the other structurally or by means of cupboards or lobbies arranged to form baffles. If teaching rooms occur in the same block as practice rooms they ought to be placed at the ends and dissociated from the practice rooms.

TECHNICAL COLLEGES

Technical colleges tend to be thoroughly bad and need a new attitude on the part of designers and building committees. How well we who lecture to evening classes know the echoing corridors, the grim reverberant classrooms, the traffic noise without, the brush scream from an adjoining laboratory, and as a result the extra effort on the part of lecturer and students to convey instruction and absorb it intelligently (Fig. 3*a*).[1] Yet these dismal buildings are all the University that thousands of young men and women know under our present system. And now technical colleges are to be built where trades of all kinds are to be taught, including joinery machine shops, and sheet metal shops, which are literally of the noisiest. In the future it is probable that diesel engines, punching machines, motor engineering trades, printing presses, butcher's blocks, will all be found contributing noise, and on the same site as classrooms where teachers are trying to teach. *Here some attempt at grouping*

[1] I gratefully acknowledge the work of the student (unknown) who did this sketch (*Fig. 3a*) for me before the war.

the noise sources, and defending the classrooms and lecture rooms is essential. Classrooms and laboratories where delicate instruments must be kept free from vibration, ought to be placed in a building separate from testing rooms and machine

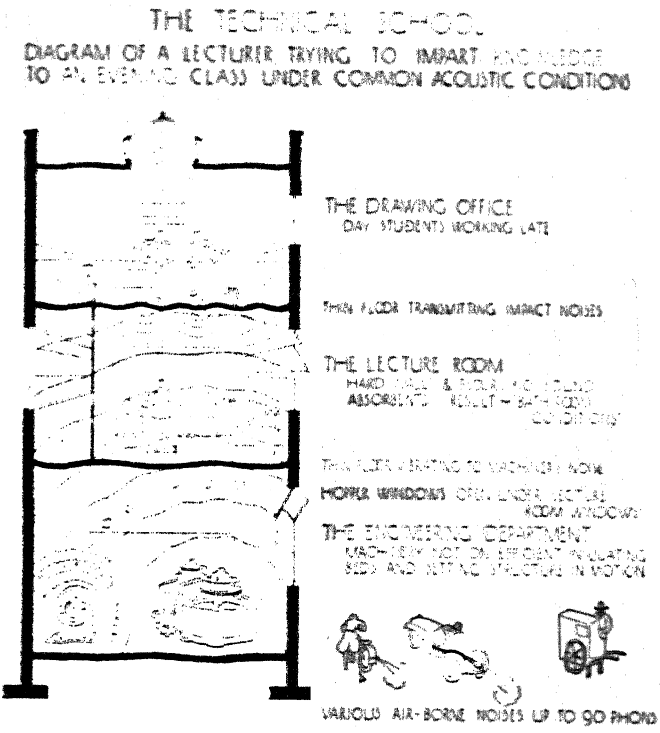


Fig. 3*a*.—Diagram to illustrate some Common Noises in a Technical School.

shops. Also the humanities ought to be given an honourable place, not relegated; and students' union rooms, common rooms, library, and college hall be planned separately in a building, or wing, which would be, and look like, a home for the mind, and would give some peaceful and cultured conditions. If this is not done the progressive de-humanizing

and standardizing of youth in technical institutions is unavoidable. Also the amount of knowledge necessary to be assimilated nowadays, if standards are to be maintained, demands conditions more favourable to learning. Therefore the teaching rooms, besides being defended from noise, need to be more comfortable and require some sound absorbing treatment to reduce the irritating reverberation caused by hard modern plasters and hygienic flooring materials. The new classrooms and hall at Morley College by Mr. Maufe are an example of what can be done, even upon a noisy site, to give more humane conditions (see also school and college halls below, p. 103, and the section 'Noise and the Efficiency of Workers,' p. 17).

THE VILLAGE COLLEGE

These buildings combine the functions of a senior school and adult community centre. The school may draw from a number of villages and may be a mixed school of between 200 and 300. At the same time the buildings are used for public meetings, concerts, lectures, cookery demonstrations, adult physical training and continuation classes: they will serve also as the headquarters of the local clubs and societies and the county branch library will also need a room in the building. Now many of these activities must necessarily be going on at the same time. Therefore group planning, and the relation and *dissociation* of groups is necessary. In the country, on unconfined sites, this can be done, but requires a different attack and general attitude to that of designing on tight city plots. A village college ought, in character, to be a nicely related series of one-storey buildings, rural in character, and spread out and linked over a fairly wide area, which provides also school gardens with a glass house and frames, playing fields, a paved playground, a small car park and cycle store. Buildings looking like factories are not appropriate and are less easily kept in repair in rural areas. Planning against noise suggests dissociation of the gymnasium and workshop, which are common to both children and adults, from the classrooms, hall, adults' common room, club room, library and caretaker's flat. But the hall itself will be a source of noise

during rehearsals, but could be baffled by kitchen, which must be located so as to serve both hall (for children's lunches and local dances) and the adults' common room. Again there are a group of rooms—namely, relatively quiet science room, domestic-science room, art room, lecture rooms and library, which will be common both to children and adults and which must not come near workshop and gymnasium. Hence a number of entrances, yet initial direction of the children, and the linking of groups by covered ways is suggested.

HUT AND CAMP BUILDINGS

Here the same principles as for hut hospitals (above) must be applied in the matter of segregating sources of noise—service yards, kitchens, transformer and motor generator rooms, accelerator pumps, air compressors. Similarly, defend administration and teaching rooms and medical officer's and inspection rooms. For hut dwellings note the need for two-leaf party walls as for houses (above, p. 20), and in communication and access corridors the value of a solid rather than a board and batten floor against footsteps. For protecting dwellings and administration blocks from noise from adjoining windows the principle of the projecting external screen wall between units, as for houses in rows (see Fig. 3) can be developed and where casement windows are used they must not open towards each other. Some control of amplification of wireless sets is desirable. Games rooms, carpenters' shops, skittle alleys, gymnasia, assembly halls, are noisy and need to be grouped away from dwellings and teaching rooms, as for village colleges above.

MUNICIPAL HALLS

Here two tendencies in modern planning are in conflict: the tendency to plan a greater and lesser hall communicating for social assemblies and at the same time to hire out these two halls separately for use at the same time. This presents great difficulties. A large double door or sliding partition between the two halls cannot in effect insulate powerful rehearsal noises. A small hall let to amateur players (now

very common) allows of the knocking up of scenery which is very difficult to insulate and may interfere with concerts proceeding in the large hall: conversely, a concert rehearsal may penetrate a theatrical performance adjoining. Good planning will separate the halls entirely. By that means they can be let on a commercial basis. This principle ought also to be applied to 'community buildings', where a number of activities requiring different halls, lecture rooms, or club rooms are carried on at the same time and adjoining rooms may be let simultaneously.

OFFICES, BANKS, BUSINESS PREMISES

Good evidence points to a real increase in efficiency for clerical workers as between quiet and noisy conditions in offices. The first cause of complaint, and exasperation, rises from trying to do business on the telephone in noisy general offices. Therefore grouping is necessary. It may take the form of placing those who buy and sell on the telephone in a relatively quiet room, or of taking the tabulating and punching machines out of the general office and isolating them. Again and again I have found the quiet rooms having a high habitable value, filled with stores; and unfortunate persons struggling along in the noisy rooms in the besieging roar of the traffic and trying to interview prospective customers above a 'threshold' of 50 db. Where there is reading, dictation and verifying aloud, quiet is necessary. Thus, in banks, the calling of the ledgers will take a shorter time and mistakes be avoided in quiet conditions. The planning of secretaries' and managers' rooms, rest rooms, and medical officers' rooms, on the quiet side is an obvious advantage. When traffic noise is serious then air-conditioning and closed windows may be necessary. The top floor then has an advantage since it can be wholly top lit. In the case of auction rooms business can be seriously damaged if bids are not heard and an air-conditioning system with closed windows may be necessary on the street front. Auction rooms also present the extreme case for a *floor finish quiet underfoot*: but it applies in all offices. In a general office gangways of rubber or cork can be usefully laid down.[1] In

[1] For floor finishes see below, p. 47.

monumental offices and banks rubber floors ought to replace the marble. (Note: for details of quiet equipment, etc., see Noise Abatement League, Pamphlet No. 9. 'Reduction of Noise in Offices, Banks, Business Premises, etc.')

PLANNING OF PIPE SHAFTS

In modern buildings the domestic services are so extensive and ramified that their planning on confined sites is now a major problem. Pipes, trunks, ducts, conduits, special services, are potential sources of noise because they are liable to penetrate floors, walls, partitions. It is still common in practice to find an expensive soundproof partition rendered useless by a service pipe breaking through it. Therefore pipe shafts must be well placed and ample in size; they are as important as staircases and ought to be located on the sketch plans. Similarly on section, horizontal duct-ways must be envisaged, or else sufficient thickness for a double floor or slung ceiling, in order to enable leads to reach points laterally without cutting through floors and partitions. Also space for an ample air-inlet shaft must be provided to prevent high air speeds and consequent structural vibration.[1]

[1] At the conclusion of this chapter I can hear the sorrowful question—how afford it? Better quality equipment, solid structure, careful slow labours by the trades, more time, more trouble, a craftsman's attitude: all that means expense. One answer is—eliminate the 'luxury' installation, the ingenious useless gadget, the *objets de salesmanship*—comforts that do not comfort the heart. Have fewer and better things.

II

PRACTICAL SOUND-PROOFING

DESIGN POINTS IN SOUNDPROOF CONSTRUCTION

IN SPECIFYING soundproof partitions for sets of adjoining rooms along a corridor, such as hotel bedrooms, one-room flats, hostels, clubs, it is not enough to consider only the transverse partitions between rooms. *Flanking* transmission always occurs along the continuous corridor wall and may make the 'soundproof' partitions useless. Therefore provide double transverse partitions but break the corridor partition at the cavity and mask the cavity by a fillet secured to one side only (Fig 4). See also Fitzmaurice and Allens' Fig 18.

The prevalence of flanking transmission must always be borne in mind and sound originating in a particular room can be conveyed long distances, not only by corridor walls, but by all the walls as well as by floor and ceiling. This is one of the vital principles which has emerged from recent studies in sound transmission.

For this reason complete structural sound-proofing requires a true system of separated units known as *Box Structure*. This has been carefully studied by Fitzmaurice and Allen (*op. cit.*) and their results can be briefly summarized as follows.[1] Taking the case of a block of two and three bedroom flats (Fig. 5) the chief noise sources are noted, namely staircase, lift, pipe shaft, kitchen, bathrooms and W.C.s. These units are left in contact with the frame structure. Insulation is then provided for the units needing quiet—namely, bedrooms, living-room, corridor and hall, and these form either one or two separate box structures according to the size of the flat, resting on a strong floating

[1] My thanks are due to these two authors who have generously permitted large extracts on this subject to be included in this chapter.

floor. The advantage of this is that the comparatively expensive insulation is limited to the necessary minimum. It is recommended that partitions between rooms in the same flat be stud partitions. Details are shown in Fig. 5*a*. The floating floor is a 'B.R.S. floor' consisting of a 2-in. concrete slab reinforced at mid-section, and cast, over a building paper, upon the structural floor. It incorporates small sockets at regular intervals such that when the slab

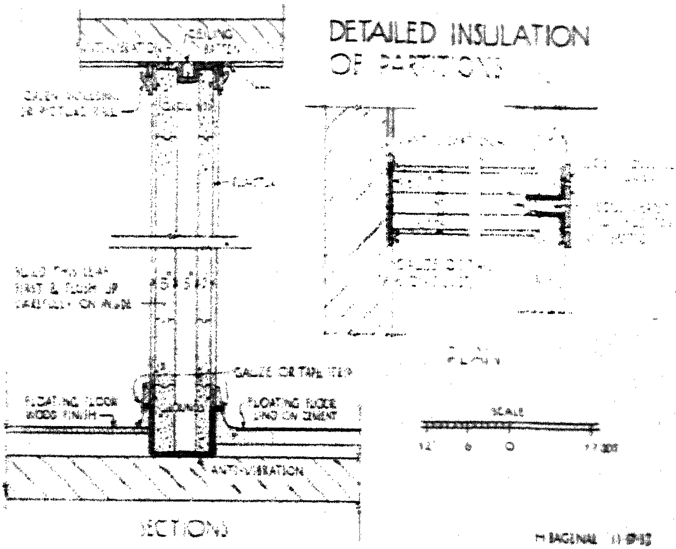
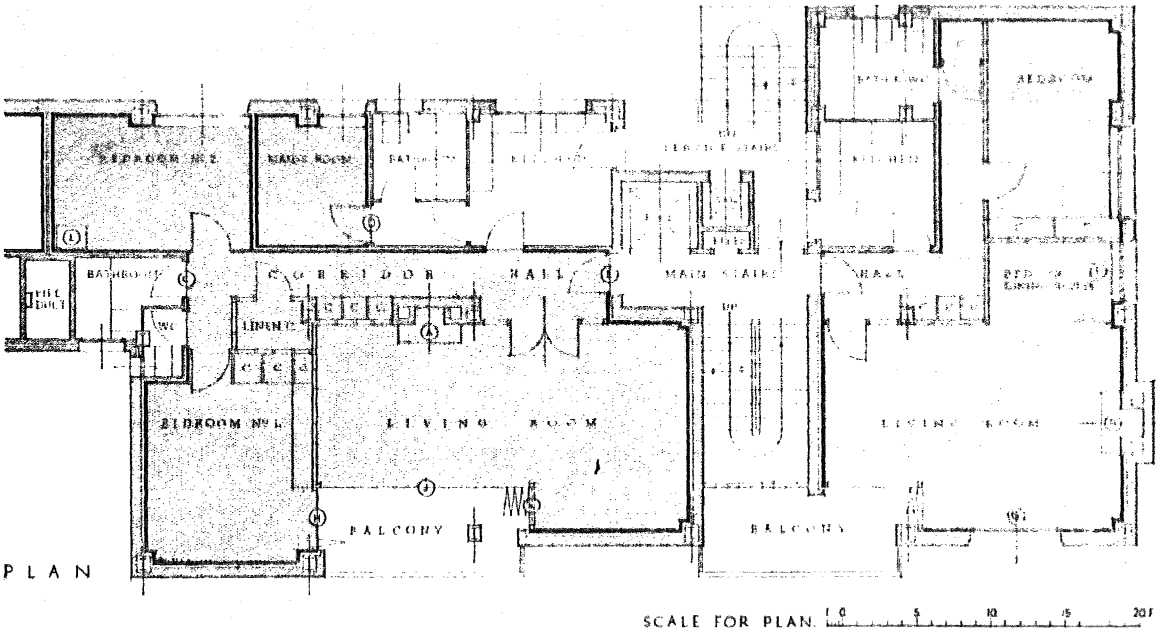


Fig. 4.—Method of Preventing Flanking Transmission along a Corridor Wall.

has set it may be raised bodily through the space of an inch above the structural floor. Rubber cubes are dropped within the sockets and the floor is raised by screwing down plugs upon these cubes. It is found in practice that large screed areas are sufficiently ductile to be lifted in this way without cracking if done in small lifts by stages. A final screed is given to receive the wearing finish. Then the partitions are built upon this floating floor in a normal manner as shown. It is found in practice that, with a heavy

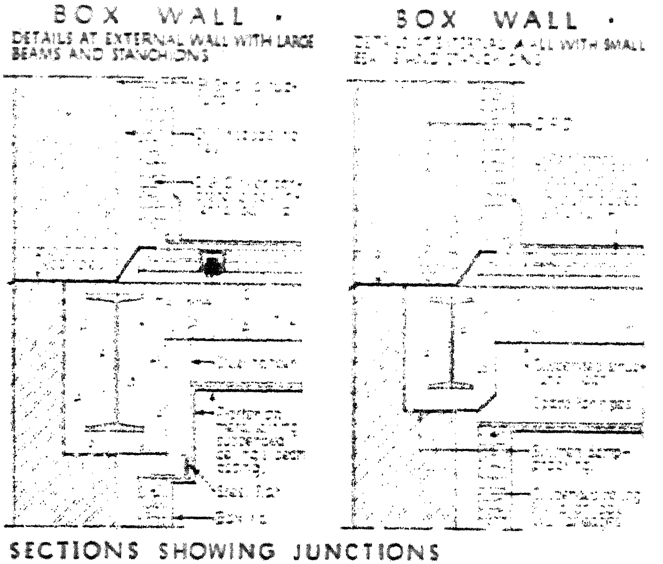


PLAN

By permission of H.M. Stationery Offic

***Fig.* 5.—Plan showing the Principle of Box Structure applied to the Design of Flats. (From Fitzmaurice & Allen.) Shaded parts show extent of Box Structure.**

floating floor of this kind, it is sufficient to hang ceilings by [illegible] hangers from the structural floor above. In Fig. 5*b* various types of box partitions are shown in detail. For party partitions between flats it is found necessary to interpose an intermediate screen partition as in Fig. 5*b* (right hand) between the two neighbouring box partitions. It was found experimentally that two adjoining box partitions communicated sound to a certain extent across the air space between



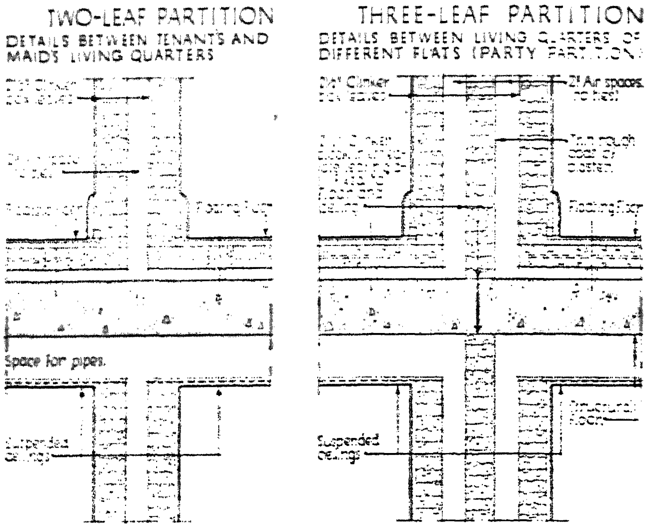
By permission of H.M. Stationery Office.

Fig. 5a.—Details of Box Structure. (From Fitzmaurice and Allen.)

them, probably owing to the fact that each acted as an extension of the floor. But the intermediate partition has only to screen, and prevent air coupling, so that it can itself rest on the frame structure. It should be noted that this method (Fig. 5*b*) of a screen wall between two dissociated box walls is the method employed for insulating loud sound sources between music studios, and can be made very efficient indeed. But box structure needs careful detailing, in order to prevent short circuiting of noise, in respect of doors,

windows, fireplaces, stanchions, beams, plumbing: illustrations of these details are given by Fitzmaurice and Allen.

Where existing rooms have to be insulated in order to make them habitable it is possible to economize by treating thoroughly *every alternate room*: treatment which I have found useful in such cases is a wood framed lining to alternate rooms wedged up against glass silk which is made to cover



By permission of H.M. Stationery Office.

Fig. 5b.—**Treatment of Partitions in Box Structure. (From Fitzmaurice and Allen.)**

whole existing wall area but not nailed into it, and then finished with a fibre board, plastered ¼ in.; floor, a lino on felt.

Resistance to transmission of air-borne sounds of simple wall structures still depends primarily on their weight. This applies to walls, partitions, floors and to hollow block partitions. Therefore light building blocks advertised as heat insulating will not also be sound insulating. Cavity walls *with wall ties* are not better than solid walls of equal weight and in some cases may be less efficient. But *unbridged double partitions* are a recognized sound-proofing practice.

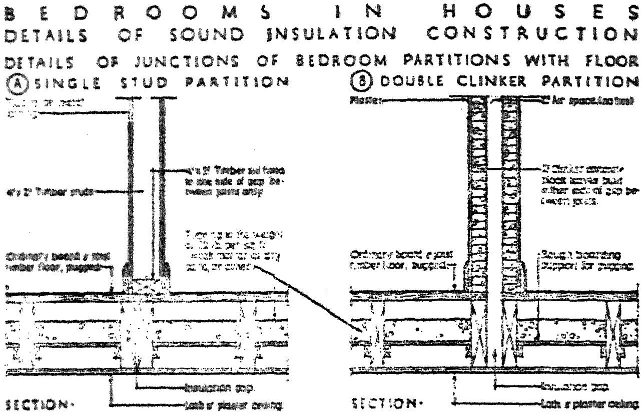
They must not be less than 2 in. apart. If the two leaves could be completely insulated from structure at margins then a double partition would be very efficient. The practical edge insulation of *double partitions* is difficult but necessary if advantage is to be had from them. They ought to act as diaphragms properly damped at their edges. Therefore ideally they ought not to rely for stability on sides and top fixings, but be able to stand alone like a 4½-in. wall. 'The ability of an edge fixing to transmit the bending moments caused by flexural vibration must to some degree be a measure of the amount of sound transmission which will take place from member to member in a structure.'[1] Therefore a double block partition ought to be just steadied against a fillet of cork or felt-covered batten at ceiling and cross walls and the bridging effect of plaster over angles must be avoided. If the partition is too light it will vibrate at shutting of doors. Therefore the factor of weight enters into double partitions as well as single walls. Another factor is the air coupling in cavities: the wider the cavity the better: where space is to be had a high degree of insulation can be got from 2-in. partitions insulated at margins if they can be placed 10 in. apart so as to avoid 'air coupling'.

In respect of *single partitions* an interesting fact, surmised from old buildings, and recently tested in the laboratories, is the efficiency of lath and plaster partitions on studs, and for that reason Fitzmaurice and Allen have incorporated them in their example of the sound-proofing of flats (*op. cit.*). The stud partition at certain frequencies comes above the "mass curve."[2] The reason is probably connected with its inherent discontinuities. 'Reductions of the order of 55 db. (that of a 9-in. wall) have been obtained at the National Physical Laboratory for stud partitions faced on both sides with a 1-in. wall board of twisted wood shaving, bound with cement ("wood-wool board" such as Thermacoust), the exposed faces being plastered with two coats of plaster.' A similar facing to a *staggered stud partition* with felt isolation at the edges and between each set of studs gave a result only a few decibels higher.[3] But heavy concrete

[1] Fitzmaurice and Allen *op. cit.*, p. 8. [2] See p. 58.

[3] For a definition of the units of noise, the decibel and phon, see Chapter III.

studs noticeably increase the efficiency. "It should be noted that whilst stud partitions are more effective than single partitions of the same weight, when averaged out over the frequency range, the improvement is chiefly at the high frequencies. There is little improvement at the low frequencies."[1] Therefore since stud partitions are not specially effective at low frequencies they are of less use against musical tones, and are recommended rather for partitions within a house, or flat unit, than for party partitions and are not recommended for practice rooms. For loud low tones



By permission of H.M. Stationery Office.

Fig. 6.—Insulation of Wood Floors and Treatment of Partitions. (From Fitzmaurice & Allen.)

the mass of the 9-in. brick wall plastered, provides in my opinion the most reliable type.

In planning moderately soundproof partitions *for private houses or maisonettes,* run the joists parallel with partitions and bring two joists close together but not touching. Along the gap between these joists fix a stud partition with sill spiked to one joist only; or a double light block partition without ties and with its cavity coming over the gap between the floor joists (see Fitzmaurice and Allen), as illustrated in Fig. 6.

[1] Davis and Morreau, Building Research Special Report. *Reduction of Noise in Buildings*, p. 19.

Note the floor boards are, of course, broken in each case. This is an application of the principle of dissociated structure.

A thoroughly practical table of sound insulation values for walls arranged in order by the late C. J. Morreau is given overleaf.[1] It should be noted that the figures in the first column are measurements in decibels (db.) of the reduction of the sound, as compared to intensity of source, effected by the particular partition. This is called the 'reduction factor' of the partition (see p. 64).

If *building-board partitions* on studs are employed they can be effectively increased in insulating value only by using them in combination with a building blanket or quilt over the whole area of the studs. In addition ¼ in. of plaster on the boards will improve insulation even if some cracks appear.

It is clear from the above considerations that the *Purpose of Partitions* must be considered in acoustic design. Hence a building-board and quilt partition is useful in places where conversation and office noises only are the sound sources: they will not serve against musical tones. At the other extreme a 9-in. wall at least is required to reduce the sound from an organ because where loud low tones are encountered weight of walling is essential. In hospitals and schools 4½-in. solid brick walls make the best partitions. In hotels double partitions having a 2-in. and 2½-in. leaf separated by a 2-in. air space without wall ties, and with some marginal insulation, are desirable.

In all partitions there is a *loss of efficiency with increase of area*. This is owing to decrease in rigidity and increase of diaphragm action, which is by far the largest factor in ordinary transmission. Large area partitions can easily give a reduction factor less by 5 decibels than a small area partition of the same specification. A discussion of the stiffness factor in sound transmission is given, p. 56.

Another important point in soundproof partitions is the *caulking* or *sealing* of openings. A sash window very

[1] See C. J. Morreau, 'The Prevention of Noise Transmission in Buildings', *R.I.B.A. Journal*, December 6, 1937. The student is referred to this short paper both on account of its useful contents and as an example of an admirable presentation of practical findings drawn out of theoretical data in a difficult subject. Morreau's death at an early age is a great loss to British technical studies.

slightly opened on a noisy street illustrates the effect of free air passages. Block partitions are liable to settle slightly, if rapidly erected, and leave a crack at ceiling

SOUND INSULATION AFFORDED BY WALLS IGNORING FLANKING TRANSMISSION

Approx. Insulation db.	Construction.	Approx. Weight lb./s.f.	Condition in Fairly Quiet Room behind Wall.
55	9-in. brickwork plastered.	85	Ordinary conversation inaudible.
	Double 2-in. clinker concrete, edges of both leaves isolated by ½-in. cork board, plastered.	33	Loud radio music and speech clearly audible.
	Plastered wall board of wood shavings bound with cement on wood or concrete studs.	20–30	
50	4½-in. brickwork plastered.	45	Loud conversation audible.
	3-in. reinforced concrete.	45	
	Double 2-in. clinker, no edge isolation.	33	Radio music clearly audible.
	Lath and 3-coat plaster on wood studs.	17	
45	2-in. - 3-in. clinker, concrete, plastered.	20–30	Ordinary conversation audible.
	Hollow blocks, plastered.	20–30	
40	Slabs of wood shavings bound with cement, plastered.	15	Loud conversation intelligible.
	Unplastered fibre board on studs.	5	

level. Sound will find its way through openings. Also it is useless to put a door of ordinary type in a soundproof partition, or to pierce the partition with free openings for

plumbing, hot-water pipes and ventilation ducts. Unless insulation is consistent, it is not worth spending money upon it.

Sound-proofing by means of fabrics has been employed in ships and aeroplanes with some success. It is difficult, however, to apply the results to buildings for a number of reasons. In aeroplanes the threshold noise and the loudness levels dealt with are so high that they can scarcely be compared, and in ships there is generally a threshold of sustained mechanical noise which is taken for granted, and the sound-proofing has to secure only a relative degree of quiet. But a high degree of insulation for tones high in pitch can be had by ply partitions of fabric and building board, separated by air spaces. A partition of this kind, consisting of layers of building board, canvas treated with special paint and coir fibre matting gave, on test, a reduction of 80 db. at 4000 cycles, but only 10 db. at 200 cycles.[1] But a pitch of 200 cycles is only a few intervals below middle C on the piano, so that a partition which is almost transparent to sound at that pitch would be practically useless for building purposes. The fact that 'this system gave eminently satisfactory results on the S.S. *Queen Mary*' indicates that middle to low tones tend to be masked on ship-board by threshold noise. But it is misleading to say that these results constitute 'wonderful insulation values higher than those of an ordinary brick wall.'[2] In temporary or emergency sound-proofing it is possible to fill in an opening with 3 or 4 layers of quilt or building blanket making a ply with building board: edges must be sealed. Also fabric hung in the air space between double partitions has some value when the partitions are thin: but here again experiment seems to show that for the lower frequencies it is almost negligible.[3] As the thickness, and weight of leaf, of partitions is increased the value of the fabric in the interspace probably becomes

[1] Barker, S. G., 'Sound-proofing of Walls'. Paper read before the London Congress of the International Association for Testing Materials, 1937. Reprint.

[2] Barker, S. G., *op. cit.*

[3] See Constable, J. E. R., 'The Effect of an Acoustically Absorbent Lining upon the Sound-insulating Value of a Double Partition'. *Proc. of the Physical Soc.*, Vol. 48, p. 695. 1936. Dr. Constable's experiments were confined to thin aluminium and steel partitions.

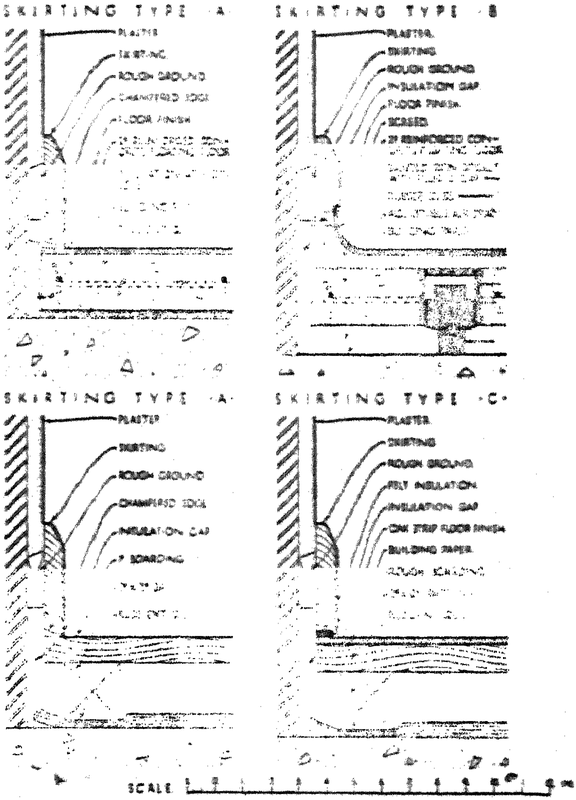
[illegible]. In cases of thin double partition, where the cavity has a hard surface, a fabric fixed to the surface improves insulation by reducing air coupling in the interspace. This has been found to apply specially to the reveals between double windows: and this fact suggests that it is enough to line the marginal surfaces: but the absorbent must be thick. In double wall partitions it would apply to cases where a hard block was used and the partitions fairly widely spaced. In a 2-in. air space only, between ordinary block partitions, tests have not always shown a useful increase due to an interposed fabric hanging. But a loose absorbent board in the interspace has been found an improvement. Dr. Möller of Budapest says that in his own buildings he specifies 'a double partition resting on 1½ in. soft cork, with 2 layers of a fibrous board inside not fixed to either of the walls; along the main walls the (total) partition is sunk into chases lined with the same board; at the ceiling there is again a strip of cork, and the cove at the ceiling is made of canvas and plaster of Paris. One of the walls is of gypsum slab, the other of burnt brick, so that they should not have the same self frequency.' [1]

FLOORS

The ordinary concrete or pot floor will of itself defend against air-borne noise but is almost transparent to impact noises. The chief requirement to-day is some inexpensive structural floor combination suitable for cheap flats and working-class dwellings. The 4½-in. 'filler joist floor' is quite inefficient against impact noises. In Fitzmaurice and Allen (*op. cit.*) a useful diagram is given on page 15 showing floors in order of soundproof efficiency placed opposite the building type that requires that minimum degree of insulation. Any floor falling above that level on the diagram should be adequate, any falling below inadequate. Opposite and just above the Ministry of Health Departmental Committee's suggestions for working-class flats occur the following (and in each case the floor specified is taken as resting on an adequate structural floor): (1) A 2-in. concrete floating

[1] Möller, C., 'Experience in Sound Insulation'. *R.I.B.A. Journal*, January 18, 1936.

floor (or reinforced cement screed), on glass silk quilt covering whole structural floor. (2) Ditto, on eel grass quilt over whole structural floor. (3) Timber raft on 1-in. rubber cubes. Just below that level on the diagram occur 'sheet



By permission of H.M. Stationery Office.

Fig. 7.—**Types of Raft Floors.** (From Fitzmaurice & Allen.)

rubber on sponge rubber finish' to the structural floor. The raft floors are illustrated with permission in Fig. 7. The floor covering to the floating concrete types can be taken as linoleum on a mastic. The illustrations show

the defence against bug cracks at skirtings and also the very careful defence against edge transmission. It is essential that the floating portion shall not touch structure at margins. A still more efficient floating floor is the 'B.R.S.' floor already described (p. 35). This will carry partitions, and is used in the 'discontinuous construction' recommended by Fitzmaurice and Allen. The timber raft on insulating cubes is more efficient if loaded by some means as in the case of Messrs. Cullum's patent floor, and the loading prevents this floor from 'dancing' (p. 48). The experience of the writer has convinced him that sound-proofing needs stronger structure throughout if insulating elements and heavier partitions are to be carried.

True isolated joist ceilings, hung up on felt insulated hangers or clips, are useful. If not insulated they can be negligible in their effect. Also such ceilings require to be of lime plaster on wood lath, or of hard plaster on metal lath, a plaster board or building board ceiling, with skim coat, is not, in the writer's opinion, worth the expense.

The insulating of timber floors (see Fig. 6 above) has been illuminated by some recent tests. Pugging was found useful if it was at least 20 lb. per sq. ft. in weight, that is to say about 3 in. deep on wood trays between joists. It can consist of weak mortar, or dry sand, or ashes. An insulation gain of 5 phons was obtained. This added efficiency is due partly to increasing weight and to reducing the diaphragm action present in all floors, and especially active in wood floors. It must be noted that light soft pugging is useless.

A greater efficiency was got by placing across the joists a raft floor of floor boards on 2-in. by 2-in. battens, resting on glass silk blanket or eel grass quilt and *not nailed through.* Approximately a gain of 10 phons was got by that means.

When pugging plus raft floor was used a gain of 15 phons was obtained. It should be noted that a practical difficulty arises in that the floating part of the floor is liable to dance and must not be nailed through. For rooms of moderate dimensions, however, this difficulty can be avoided by spiking the battens into a stout wood framing round the margins of the rooms, thus increasing

the weight, but taking care not to wedge up against structure: the glass silk, or building blanket, must be brought up to under side of skirting in order to ensure the edge insulation. This type of floor has been done successfully in small blocks of flats. The old method of separate ceiling joists below floor joists is also a thoroughly useful method, but is more efficient if the ceiling joists have insulated bearings, that is to say, if they are placed on cork strips. In all cases of ceilings thick lime and hair plaster or dense cement plaster is more efficient than the wall board or plaster board type.

Insulation tests on wood floors point to increase of weight and stiffness if sound-proofing is to be effective. Therefore floor joists, in the author's opinion, require to be heavy: the increase in noise complaints in houses in recent years is partly due to the light 9-in. and 7-in. joists and to the actual bending of floors under the loads added by partitions, thus increasing diaphragm effects. The table overleaf showing floors arranged in order of efficiency is taken from C. J. Morreau (*op. cit.*).

NOTES ON FLOOR FINISHES

The following notes summarize and amplify the information on floor finishes relative to various buildings already given.

Hard floor finishes developed for the main purpose of durability and anti-abrasion in factories and commercial buildings are not generally suitable for the requirements of residential buildings owing to footstep noises and clatter.

The function of a floor finish in residential buildings is to reduce by cushioning action the loudness of impact noises at their source. Therefore the close carpeting of flats and the use of strip carpets in corridors is one of the first remedies for noise nuisance in existing buildings. In new buildings thorough sound insulation by means of floating floors is the more scientific approach.

A useful cushioning floor finish for nurseries, and rooms with light weight furniture, is a stout linoleum on a thin felt. For wardrobes, etc., shoe fittings can be had that spread the weight.

ROUGH CLASSIFICATION OF FLOORS

Very Noisy Floors.	1. Wood joists and plastered ceiling, boards nailed to joists, with or without linoleum covering. 2. As 1, but with light pugging (e.g. slag wool, granulated cork) between joists. 3. As 1, but with fibre board or quilt laid over joists.
Noisy Floors.	4. As 1, but with heavy pugging (e.g. ashes, clinker). 5. As 1, no pugging, boards nailed to battens resting on thick eel grass or glass silk blanket laid over joists. 6. Reinforced concrete floor with or without linoleum. 7. Reinforced concrete floor with any hard finish (e.g. terrazzo, tiles, magnesite composition, asphalte, wood blocks), with or without rigid filling (e.g. sand, clinker) between structural floor and screed. 8. Reinforced concrete floor with boards and battens held rigidly to the concrete.
Fairly Noisy Floors.	9. Wood joists and plastered ceiling, heavy pugging, boards nailed to battens resting on thick eel grass or glass silk blanket. 10. As 1, with or without heavy pugging, pile carpet on thick underfelt. 11. Reinforced concrete floor, pile carpet on underfelt. 12. Reinforced concrete floor, boards and battens resting on pads of fibre board, thick felt or rubber or held in special clips incorporating resilient material. 13. Reinforced concrete floor, boards and battens resting on slag wool, eel grass or glass silk blanket. 14. Reinforced concrete floor, 1-in. layer of granulated cork, 2-in. concrete screed.
Quiet Floors.	15. Reinforced concrete floor, 2-in. concrete screed on rubber pads, eel grass or glass silk blanket not less than 1 in. thick. 16. As 9, 12, 13 or 14 with the addition of carpet on underfelt.
Very Quiet Floors.	17. As 15 with the addition of pile carpet on underfelt. 18. As 15 or 16 with the addition of a suspended plastered ceiling.

Two further floors should be noted. Messrs. Cullum's 'C.S.S.' floor is a loaded board and batten floor floated on 'isolators' of rubber or other elastic material and resting upon an ordinary structural floor. This is useful where a board or parquet finish is required, and when the boards are nailed down over corrugated paper the floor is quieter underfoot than an ordinary board and batten floor.

Where heavy construction is required for carrying machines, as in the case of an hotel kitchen, a floor of the type illustrated in Fig 7*a* can be used in which cement slabs are carried on insulated sleepers and ample space left for the service pipes.

Expensive cushioning or semi-cushioning floor finishes, such as rubber or cork, are only efficient if laid on the solid. If laid on a board and batten floor they only slightly reduce footstep noises. Where solid floors exist in offices considerable reduction of noise can be had by placing narrow gangways of rubber or cork carpet along lines of traffic. This applies also to corridors and wards in hospitals.

The common board and batten floor is very noisy under-

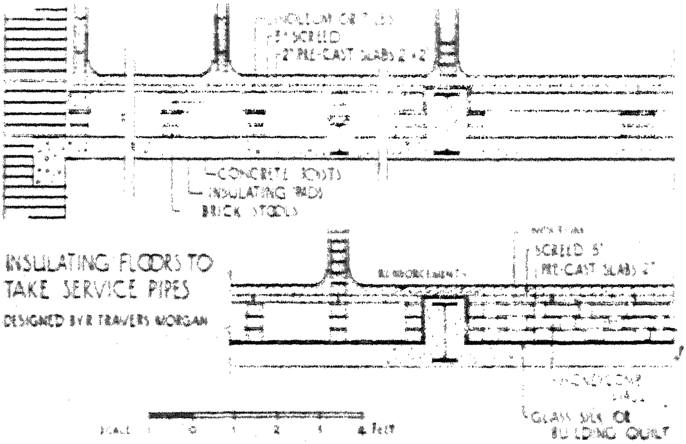


Fig. 7a.—Heavy Floor Type.

foot and is not suitable for public buildings. Where hard wear and some measure of quiet are needed, alternatives are lino on concrete, wood block, bitumen concrete, and asphalte.

DOORS AND WINDOWS

Doors tend to spoil sound-proofing schemes and require to be carefully located. They should be separated and not come opposite or adjoining. On the other hand baffle doors shutting off noisy corridors and lobbies can be useful. A door to be soundproof must be heavy to reduce diaphragm

action and also must shut close on all four sides. A crack at ground level will make sound-proofing useless. A grip latch is necessary, as in telephone boxes, to draw the door tight. A felt rebate or double rebate, like an ice-box door, is necessary: but there must also be a threshold stop or bevil. Double doors are improved by a wide space between, lined with felt, or having a thick curtain between the doors. Door linings must be carefully caulked to avoid cracks.

Windows present problems of their own. Since glass is relatively heavy for its thickness it is fairly efficient, as can be noticed by closing an inch of open sash window on a noisy street. Laboratory tests [1] on glass in a 5 ft. 2 in. × 3 ft. 10 in. opening show some useful results. A single pane window of 21-oz. glass gives an average reduction factor of 28 db.: of ¼-in. plate glass 35 db. In respect of double windows of 21-oz. glass the wider the interspace the more the efficiency. Thus an interspace of 1 in. only gives 42 db., but an interspace of 8 in. gives as much as 53 db. This shows that the air coupling between the two glass membranes is a considerable cause of sound transmission, a fact which was noted also in respect of thin partitions: but in windows the marginal bridging seems less a cause of leakage than in the case of partitions.

Glass also transmits by resonant vibration, generally at low and middle pitch, and this can easily be detected by touching a window pane on a noisy street when a tram or heavy lorry is passing. Therefore the true defence of a window is not its average reduction factor, but the reduction factor at low and middle pitch, and an inspection of test results shows that the plate glass is here the more efficient. Another factor, in the author's view, is the heaviness of the steel frame, and therefore the division into panes by added window-bars. A sash ought to combine the mass of a heavy steel section frame with ¼-in. plate glass in panes of moderate size, and this will be found to vibrate proportionately less to the low tones of heavy traffic. The new Greenwich Town Hall (architects Messrs. Culpin & Culpin) has been defended successfully against heavy street traffic noise, including trams, by single windows of

[1] Davis and Morreau, 'The Reduction of Noise in Buildings', *B.R.S. Special Report*, No. 26, p. 39. H.M. Stationery Office.

this heavy type. The evidence as to the advantage bedding the panes in felt seems indeterminate.

VENTILATION AND NOISE

Windows and ventilation are complementary problems where sound-proofing is concerned. If traffic noise is to be excluded windows must be kept shut. Attempts at soundproof open windows have been made by firms in the past, accompanied by determined advertising, but the fact remains that a shut window keeps out the sound because it does not give an air inlet. In America thought has been expended on 'soundproof' air filter units with fan, to place against a narrow opening at the bottom of the window. But windows vary in size, and the ingenuity would be better spent on a fixture unit which could be built into window breasts, and give fairly long air intakes over absorbent baffles. By that means real insulation could be secured.

In England, where rapid changes of temperature occur, people like to open the windows from time to time and then close them. Therefore in schools, committee rooms, board rooms, hotels, there is need in English ventilating practice for an 'open window equivalent' which can be switched on intermittently. In a London classroom I have known relief from noise at certain school periods to be had by closing the window frame but leaving open a single-hinged pane and turning on a small suction fan on the opposite or corridor side. Long, baffled, *inlet* trunks liable to get dirty are clearly not desirable in schools, but a pressure fan on the quiet side, or transmitting from an airy corridor, could supply air which could then escape through baffled *extract* ducts on to the noisy side. Schools do not want full air-conditioning but want some assistance of this kind.[1] In existing hotels where the old fire-place

[1] The reason why American heating and air-conditioning practice is not adopted widely in England, in spite of the urgent recommendations of engineers, is due to the rapid changes in open-air temperature in England from day to day which will often, in winter, give a warm spell in which the temptation is to throw open doors and windows: and also the actual health advantages of the coal fire which cannot burn in a room without ventilating that room. We have not an

flues exist, successful sound-proofing has been carried out by closing windows and introducing air, properly conditioned, through trunks brought down the flues from plant on the roof, and delivering through gratings in the breasting. The air then finds its way out into corridor through doors and fanlights. (See also section on hotels, p. 25.)

Fan and trunk noises have been analysed recently and can be greatly reduced. Fan noises, in order of importance, are due to air eddies caused by excessive tip speed of the fan; to vibration of the fan casing; and to the motor itself. Tip speed ought not to exceed 55 ft. per second, and outlet velocity 1200 to 1500 ft. per minute. The fan casing must be truly rigid, or it can be damped by asbestos spray or built in laminated metal with a layer of felt between. 'Super-silent' motors ought to be specified having the sleeve type bearing and not ball-bearings, and belt drives to fan. Transmission along ducts can be minimized by a canvas sleeve connection at the fan casing: but this will not serve to eliminate noise from a loud fan. Insulation of the whole plant upon an anti-vibration mat, not bolted to structure, is a vital requirement, and air-conditioning plant in the basement is easier to insulate than on the roof of frame buildings. Noise of air-surge in ducts is avoided by slow velocity (not more than 1000 ft. per minute in a duct 8 to 16 sq. ft.) and by easy bends and stream-lining. Drumming is avoided by using builders' work

'equable' climate, but a climate of rapid day to day sensation changes caused by temperature and moisture variations. When we close all our windows in the cold snaps we get from the coal fire a very rough adaptable heating and ventilating system. This is perfectly well-known to persons who have nursed children in nurseries with and without coal fires, and all night nurseries ought to have grates and flues. But this means that the coal fire has a rationale for this climate; whereas it is the throwing open of windows which upsets the air-conditioning designer and makes difficult practical problems even more difficult. But here again some distinguishing of categories is necessary. In buildings on city sites exposed to traffic noises, thorough air-conditioning is necessary to achieve thorough noise insulation. In residential buildings moderate central heating is desirable, supplemented by small coal or gas fires where required for health or good cheer, but there is also a category between these two which requires on account of noise the 'open window equivalent' in intermittent ventilation which I have noted above. Here, as elsewhere, health conditions in home and school are more important than comfort conditions in the commercial building.

trunks and for metal trunks can be reduced by using a circular section.[1]

A main ventilation trunk having branch ducts to a number of adjoining rooms can easily conduct sound from one room to another, and the stream of air against the direction of noise in a duct will not reduce transmission. This is specially important in hotel bedrooms with telephones, in practice rooms, in recording studios and in masonic lodges. The trunking must not penetrate partition walls between rooms. It may be necessary to line with felt the main trunk from which the branch ducts to rooms are led off: or a series of absorbing baffles or 'splitters' may be placed in the branch ducts. (See also section above on hotels.)

As with trunks so with *hot water pipes to radiators*: these must be planned horizontally not to penetrate sound-proof partitions on which money has been expended, and to pass through floors only in the shafts designed for them. In cases of existing buildings noise is often found to be transmitted through the ample openings in walls and floors left for pipes and not properly sealed or caulked. The accelerator or 'booster' pumps are a source of noise in heating systems, and these ought to be silent and have belt drives: they must not have axle drives which cannot be insulated.

QUIET PLUMBING

Noise in plumbing systems arises first from rapid water velocity through small diameter pipes, not stream-lined, and having abrupt changes in diameter, together with light, cheap taps and ball valves, the parts of which tend to oscillate and transmit a series of small impacts. Therefore well-designed plumbing giving large diameters and easy bends is a means of avoiding trouble. Water hammer can be caused also by rubber washers to pressure taps and can be remedied by replacing with leather washers. Another remedy is sometimes easily found by reducing the pressure of the house supply by a turn of the main supply cock, and

[1] Faber, and Kell. *Heating and Air-Conditioning of Buildings*. 1936, p. 387.

this principle can often be applied locally to a noisy storage tank or cistern. Special remedies against water hammer have been designed, such as 'air chambers', 'relief pipes' and separating units.[1] The hiss of water running through a ball valve can be prevented by an extension pipe from the valve discharging under water.

Impact noises are conveyed along pipes with very small 'attenuation'. Attenuation is the reduction in noise in proportion to distance travelled. Tests at the N.P.L. showed that pipes clamped close to the wall transmitted less than those held away from the wall in clips; also that attenuation was unaffected by filling the pipe with water; and that, on the whole, vibration is attenuated in a lead pipe more rapidly than in a copper or steel pipe tested under corresponding conditions. N.P.L. tests by the late Dr. J. E. R. Constable have also shown that serious noise transmission along pipes can be effectively reduced by inserting a length of rubber hosing in the conducting pipe:[2] but this must be in an accessible place for renewing from time to time. It was found that to insulate low frequencies some 2 to 3 ft. is required: for noises like the hiss of taps high in pitch short lengths can be used. Canvas reinforced rubber is not so effective, but is still useful for the purpose.

Now that wash-basins are provided in bedrooms there is still greater need for the proper planning of waste and supply pipes. For instance, if a row of bedrooms used by nurses on night duty are furnished with basins on the partition walls, noise is likely to be transmitted freely through the partition, and sleep is disturbed: but if placed on the main external wall, and pipes properly cased, disturbance can be greatly reduced. Thin partitions can easily act as amplifiers of noise conveyed through pipes fixed to them. Hence the need for well-planned chases and shafts. But in high buildings the chute of water in waste pipes down shafts can cause considerable noise, and the shafts in such cases require to be 4½-in. brickwork. Flushing cisterns also ought not to be fixed to light partitions adjoining bedrooms and living-rooms. It should be noted that in W.C.s the

[1] See Cleverdon. *Plumbing Engineering*, 1937, p. 23.

[2] Constable. 'The Prevention of the Transmission of Sound along Pipes'. *Proc. Phys. Soc.*, 1938, Vol. 50, p. 360.

noise of flushing can be avoided by using a syphonic pan and reliable low level flushing cistern.

For mechanical equipment noises see above, p. 26 and p. 52.

ELECTRICAL EQUIPMENT

Cheap electrical equipment tends to be noisy. In flats a chief cause of complaints is the make and break electric lighting and heating switches placed on thin partitions. In an alternating current supply a 'slow break' switch can be used and can be made comparatively quiet: or pendant switches as used in bathrooms could be more widely employed. Single-phase alternating supply is very noisy when used for operating fans, pumps, domestic motors. Also electric refrigerators ought not to be placed on party partitions. Air compressors, accelerator pumps, transformers and motor generators all require to be carefully insulated from structure and also from air-borne noise in suitable basement positions. For lifts and electrical equipment noises, see also pp. 11, 14, 23, 26.

III

ACOUSTIC THEORY FROM OBSERVATIONS IN BUILDINGS

IN THIS book we have plunged first into practical problems known to builders who may have only a working knowledge of acoustics. But from that knowledge some generalizations can be made. If we should strike with a moderate blow upon the centre of a matchboard partition, then in succession upon a 2-in. block partition, and a 9-in. plastered brick wall, we should hear a progressively duller and less loud response in the room itself. But so also would any listener on the opposite side of each. This loudness of response is due to drum action or flexural vibration of the whole partition, and the response heard in the room is clearly related to the transmission. Far the largest proportion of noise transmission in buildings is due to flexural vibration of both walls and floors. And flexural vibration is a function of stiffness, and stiffness is a function of mass and of elasticity. In our present state of theory mass is taken as the significant factor because it is found that *homogeneous walls defend against transmission in proportion to the logarithm of their weight per square foot.* This is called the mass law or mass curve. But it assumes partitions of equal area. But it is found also that partitions of the same material transmit also in proportion to their area,[1] that is, in proportion to their drum action or decreased stiffness. Therefore stiffness is fundamental to the problem. A rough measurement of stiffness is the relationship of wall thickness to wall area ; the less the thickness for a given area the greater the drum action : and extended studies on partitions of different areas may make stiffness the significant factor in which mass has always

[1] Tests at the N.P.L. showed 5 db. decrease in the reduction factor for all frequencies as between the smaller test panels (5 ft. 2 in. × 3 ft. 10 in.) and the larger (10 ft. × 8 ft.). *Ministry of Health Report on Construction of Flats for the Working Classes*, 1937, p. 43.

a predominant influence. Another stiffness factor is bonding or edge fixing, and the significance of stiffness has already been envisaged in the statement by Fitzmaurice and Allen, quoted above (p. 39), to the effect that the ability of an edge fixing to transmit the bending moments caused by flexural vibration is a measure of its inefficiency in insulation. Floors present even more marked cases of flexural vibration than partitions. It is found in some cases that they appear to transmit more impact noise to the room below than is recorded in the source room above, probably due to the fact that they are stressed drum areas, on account of their own weight, and are often of large extent relative to their thickness. In impact noises the problem is complicated by the fact that vibrations through material are added to the drum action of the wall as a whole. In air-borne noise flexural vibrations are a large factor, especially, in the case of 'box resonance' (see below). It is worth noting that as bye-laws permit thinner and more highly stressed structure so our noise problems have increased.

Again we observe that low-pitched vibration and noise excites structure so as to be felt with the hand,[1] but that high-pitched noise does not. And this is obviously related to the fact, shown by laboratory experiments, that the reduction factors of partitions decrease in value as we test notes lower in the scale.

Also we find often that a single insistent low to middle note will come through the party wall from a player upon the other side, which suggests that walls and floors, like vibrating plates in a laboratory, have a 'resonant response' at some regions of pitch, at which they react to sound energy more strongly. Now this property of a vibrating plate is defined generally as '*resonance*', and its liability to respond noticeably only at a limited region of pitch is spoken of as

[1] I first realized the implications of 'vibration' in cities fully, when measuring up St. Margaret's, Westminster, with J. W. Parr in 1928. We found at the centre of the tie beams of the roof trusses a sustained mechanical vibration picked up, through foundation and walls, from the Westminster traffic when noise itself was largely excluded. The effect of mechanized urban life is to submit structure all the time to undefined vibration, while at the same time the economic motive reduces thickness dimensions and makes structure more susceptible. Hence the very common moving and cracking of thin partitions at the top of high buildings.

'*sharpness of resonance*'. Also it has a corresponding liability to absorb energy at that pitch only, and that is called its power of selective absorption. A large slung ceiling to a wireless studio was once found to absorb sound so much at a particular low pitch that it had to be divided up into separate sections in order to reduce its selective absorption. Another property of resonant material is to reinforce or amplify sound by adding the energy of its natural vibration to the vibration of the source. It then transmits sound more loudly: and in addition tends to reinforce sound at that particular pitch in the room itself. But some materials have power to respond less sharply but over a fairly wide range of pitch. This is called 'damping'. It is these materials that are valuable for musical purposes and wood is the well-known example. Hence the use of wood both for musical instruments and also as panelling in concert rooms.

The term 'resonance' in physics is confined, as to its usage, to the reinforcing of sound by this sympathetic response, but in fact the same kind of response is associated with all flexural vibrations of structure, and in buildings, as we have noted, is a prime cause of transmission. Response implies absorption of energy and also transmission or reinforcing when amplitude of vibration has built up to a maximum.

Again we note that extreme cases of noise transmission occur between bare rooms having hard surfaces. Here theory tells us that sound in the room of origin accumulates or builds up to a maximum by *inter-reflection* between opposite pairs of surfaces, and produces in the room what is known as *reverberation*. The bare room acts in such a way as to give maximum effect to the sound energy within it. Also the volume of air contained in the room may act as a resonator and at a particular region of pitch may reinforce the sound on the same principle as does resonant structure (discussed above). This response of the contained air is spoken of as 'boom' or 'box resonance', and is noticeable in bathrooms.[1] Then, if the room has a thin partition, these combined factors

[1] It is sometimes found in small recording studios and is difficult to remedy. Also it is related to the phenomenon known as 'the note of the church'. See Bagenal and Wood, *Planning for Good Acoustics*, p. 216.

may cause drumhead action of the partition, and extreme transmission occurs. As our living rooms, classrooms, private offices, approach 'bathroom conditions' through the use of hard plasters and floor finishes, so they illustrate all the acoustic phenomena and produce ever more uncomfortable conditions.

In Fig. 8 the facts we have noted are illustrated diagrammatically. When sound strikes a wall loss of energy occurs by absorption and by transmission, and the remaining energy is reflected. In (1) is shown a 9-in. brick wall in cement, plastered, reflecting a large percentage of the sound beam falling upon it and transmitting only a very small fraction. In (2) a porous material like a weak breeze block unplastered, with many cracks, is transmitting some of the sound through air passages, absorbing some in the interstices of the material and reflecting the remainder. In (3) a 2-in. light block partition is transmitting by flexural vibration: here experiment seems to show that if a beam of sound is focussed at an angle upon it, as illustrated, there is both beam transmission and also at a particular region of pitch the whole wall will vibrate like a plate (represented diagrammatically by the partition taking a wave-like line), and will transmit very roughly normally to its surface, as shown by arrows. In (4) absorption is illustrated; here a thick mattressing (4-in. rock wool) upon a 9-in. wall absorbs some 80 per cent. to 90 per cent. of the sound energy, the remainder being partly absorbed in the wall interstices and converted into heat and partly reflected. In (5) is shown the resonant action of wood panelling over a range low in pitch: here again beam reflection occurs also, but probably proportionately less in those regions of pitch where resonance occurs. The radiation of energy normal to the resonant surface is represented by arrows here as in (3). In (6) reverberation is very roughly represented filling the whole room with sound and building up to a maximum: it can be seen then that the whole room becomes a source—like a musical instrument with its resonator—and acts with increased strength upon the thin partition which at a particular pitch will transmit powerfully like a drumhead. Also in such a case a wave train of a particular wave-length (pitch) may exactly fit between opposite walls and this is spoken of as the phenomenon of

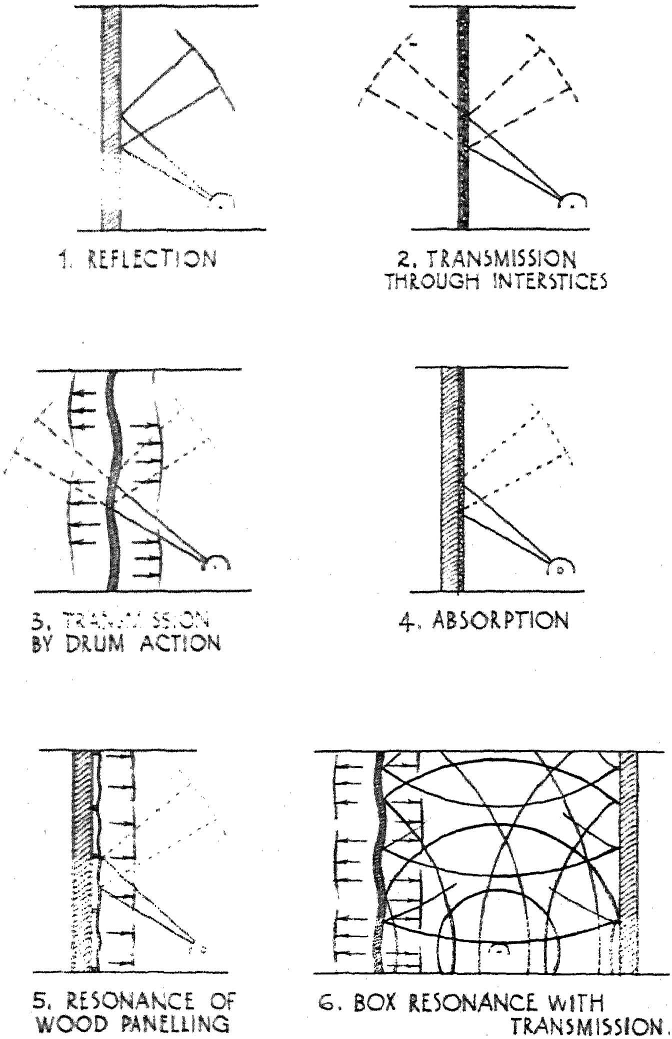


Fig. 8.—**Acoustic Phenomena illustrated.**

'standing waves' or response of the air cavity. Then 'box resonance' or 'boom' will occur in the room.

But also if we should play a quartet or sing a madrigal in one of these bare rooms we shall find that the effect is good. Musical tone is improved, up to a point, by reverberation in a room: this agrees with the fact of choral music sounding well in churches where reverberation is long, so that the need for some measure of reverberation in concert halls and music studios is understandable. And in music studios where accurate recording is to be carried out it must be noted that the effect of resonance-absorption and 'boom' (as noted above) have to be taken into account as well as reverberation and the absorption of soft materials.

Organ builders have empirical knowledge of acoustics, and it is said that Bach who designed several types of musical instrument could foretell what would be the effect of a particular room upon tone. The late Mr. Norman of Messrs. Norman & Beard taught me some valuable things in acoustics. In surveying a church before designing a new organ he would first clap the palms of his hands to give a relatively lower note, and then the fingers of his hands to give a relatively higher note and compare very roughly the length of reverberation in the two cases. He said that this gave him a first idea as to the relative balance of treble and bass pipes; and that the larger the area of glass in a church the more he must reinforce the bass. This was because glass transmits low tones and therefore acts on them as an absorbent. This unequal absorption of a building at different regions of pitch is called *selective absorption*, and is found to a greater or lesser degree in all rooms. Organ builders prefer pure reflection from solid walls giving simple reverberation, and do not like resonant panelling which both absorbs, and responds, to tone in an unforeseen manner. Again an organ does not sound nearly as well in a crowded concert hall as in a church because of the considerable absorption of audience, carpets and upholstered seats which reduces the reverberation. For this reason the cinema organ relies on its loud reed stops to produce dramatic effects and compensate for the lack of the enhancing of tone given by reverberation. But the organ has always this advantage: it can be designed for one auditorium only and the selective

absorption of the building over the musical scale can be compensated for in the instrument itself. In the case of a music studio the studio itself must be designed to give approximately the right absorption at treble, middle and bass to ensure the proper reverberation over the musical scale and the proper balance of tone for average instruments. This too is the problem of the modern concert hall. It is further developed in Chapter VIII on designing for musical tone.

Let us at this stage draw a distinction between that class of problem in which 'reverberation' is associated with noise and undesirable conditions as in lecture rooms, living-rooms in flats, etc., and the class in which a carefully designed reverberation condition is aimed at as in concert rooms and music studios.

We are now in a position to define more carefully some acoustic phenomena with reference to the behaviour of sound in buildings. 'A vibration has two important characteristics—*frequency*, which is usually defined as the number of vibrations per second, and *amplitude* which is the maximum distance through which any point in a vibrating material is displaced from its position of rest. If the frequency of the vibration is increased the pitch of the sound will be raised. If the amplitude of the vibration is increased the sound will be louder.' [1]

Resonance of structure might be defined broadly as its reaction to sound energy through flexural vibration. It is defined by Fitzmaurice and Allen as follows:

> 'Any building element, be it wall or floor, when subjected to some disturbance such as a sound wave in air or a blow, tends to vibrate more readily at certain frequencies than others. The lowest frequency of such vibration is termed the "natural frequency" of the structure, and the range of higher frequencies corresponds to a series of vibrations which are multiples of the natural frequency. When the frequency of the sound wave in air impinging on the structure corresponds to the frequency of the structure, a state of "resonance" is said to exist; and less sound energy is required to build up a large amplitude of vibration in the structure. Consequently sound is transmitted more readily.'

Box resonance is the reinforcing of the source of sound in a room by the natural frequency of the enclosed volume of air in the room.

[1] Fitzmaurice and Allen, *op. cit.*, p. 2.

Reverberation is the building up of sound from a source in a room to its maximum 'energy density' by inter-reflection [illegible] its dying away after the source has ceased: [illegible] can be measured by noting the time of dying away in seconds (see Chapter VI.). In common parlance the term resonance is often used when reverberation is intended.

Absorption at the surface of a structure is the causing loss of sound energy at that surface. It is caused by transmission into the structure or beyond it, and also by conversion into heat by dissipation in the interstices of the structure or in overcoming the internal friction which resists vibration.

Damping can be defined in general terms as the frictional resistance of a material to vibration over a range of pitch.

UNITS OF MEASUREMENT

Now in comparing either reduction factors of partitions, or periods of reverberation in halls, it is obvious that some suitable unit of sound is required if quantitative measurements are to be taken. The mechanical energy can be measured by instruments in a laboratory [illegible] also the ear can roughly assess the sensation [illegible] subjectively above an arbitrary standard. To relate these two ways of measuring was a difficult problem in modern physics. It is clearly and briefly described by Dr. Davis of the National Physical Laboratory as follows: [1]

'The ear is sensitive to a wide range of frequencies of vibration —from about 20 to 20,000 cycles per second. A frequency of 261 cycles per second corresponds to the pitch of middle C on the piano. Doubling the frequency raises the pitch of the tone by one octave. The degree of sensitivity of the ear varies throughout the frequency range, being low at low frequencies but increasing with increasing frequency to a maximum of about 1000 cycles per second, after which it falls off again. In other words the same mechanical energy put into sounds of different frequencies will not cause the same sensation of loudness in the ear. Consequently different units are used for expressing the energy of a

[1] Davis and [illegible], 'Reduction of Noise in Buildings', p. 2, *Building Research Special Report No.* 26. H.M. Stationery Office, 1939. The student is referred also to Dr. Davis's [illegible] for a short clear presentation of acoustic theory, and to Dr. Alexander Wood's *Acoustics*, Blackie, 1940 [illegible]

sound and the loudness. For expressing the mechanical energy of a vibration, or sound, and comparing it with that of others of the same type the *decibel* is the unit employed. For expressing the loudness sensation in the ear, the unit employed is the *phon*. . . . The phon is approximately the smallest loudness change which is detected by the ear under ordinary conditions. A reduction of loudness of 10 phons is often subjectively assessed by an average person as "halving" the loudness for sounds of medium pitch and loudness."[1]

The decibel is therefore a unit of energy to be measured on an instrument; the phon a unit of loudness as perceived by the ear. For sounds of moderate loudness, and pitch round about 1000 cycles, decibel and phon are the same standard and *both* represent approximately the minimum increase of sound the ear can detect. And where noise measurements of the insulation of a wall or floor are made by comparing energies measured on the source side and then on the receiving side, that is where they are *differences* between measurements, it is clear that either unit can be used. Therefore we find the 'reduction factors' given by partitions or floors (see p. 42) tabulated as in decibels or in phons.

The table opposite is a scale of ordinary noises in phons, selected from various authorities.

Thus two units—decibel and phon—enable us to observe quantitatively and to relate in our minds measurements of sound energy with their loudness equivalents assessed by the ear. On the sensation scale we tend to take the loudness of the speaking voice, about 60 phons, as a reference, and we implicitly compare an interruptive noise to that reference when we say 'I had to raise my voice'. It should be noted

[1] Scientific definitions of decibel and phon are as follows:

Decibel. Two sounds of the same character and of intensities I and I_0 (energy units) differ in intensity by n decibels (db.) when $n = 10 \log_{10} (I/I_0)$. A reduction of 1 db. is a reduction of the mechanical energy in approximately the ratio 1·26 to 1. A reduction of 10 db. corresponds to a reduction of the mechanical energy to one-tenth of its original value: a step of 3 db. corresponds to a reduction of one-half.

Phon. A sound is said to have an 'equivalent loudness' of n phons if the sound is judged by a normal observer to be as loud as a 1000 cycle pure tone of which the intensity (energy content) is n decibels above a fixed zero which is almost identical with the threshold of hearing, namely 0·0002 dynes per square centimetre. (See *British Standard Glossary of Acoustical Terms and Definitions*, No. 661, 1936.)

that public speech is often down to 40 or 50 phons nowadays, and that this is one cause of acoustic complaints. Loud-speakers in cinema theatres are up to 70 or 75 phons. Concert music traverses the whole loudness scale from the

Rooms and Localities.	Equivalent Loudness in Phons.	Common Noises.
	130	Threshold of Pain.
	120	Noisy Aeroplane Engine at 10 ft.
Boiler Maker's Shop .	110	
Noisy Tube Train Aeroplane Cabin .	100	Pneumatic Drill, unsilenced. Noisy Sports Car and Motor Bike. Express Train at 12 ft.
Very Noisy City Street	90	Pneumatic Drill, silenced. Motor Horns, Loud Music.
	80	Trams. Accelerating 'Buses. Loud Radio Music.
Cinema Theatre . Average City Street Noisy Office . .	70	[illegible] [illegible] [illegible] Loud Public Speaking.
Room with Ordinary Conversation . Quiet Street . . Train Windows Closed	60	Normal Speaking Voice. Noisy [illegible]
Quiet Office . . Quiet Restaurant	50	Quiet Saloon Car. Upper Limit of Household Noise.
Quiet Suburban Street	40	Low Radio Music.
Quiet Garden . .	30	Average Domestic Noise.
	20	Whispering.
	10	Rustle of Leaves in Slight Breeze.
		Approximate Threshold of Audibility.

delicate pianissimo of strings to effects of 100 phons or more, such as are achieved by a regimental band performing Tschaikowski's '1812' overture with *obbligato* of real guns and rockets.

In *threshold noise* we note that quiet home conditions are 30 to 40, and a noisy city office as much as 70. 'Thresh-

old ' has already been referred to (p. 8) as the familiar noise of ordinary affairs in a room, to which we grow accustomed and of which we do not as a rule complain. Annoyance caused in a room by a particular intruding noise through a wall or floor largely depends on the threshold noise already existing in the room itself. The threshold noise *masks* some of the intruding noise. Now experiment shows that very roughly the intruding noise to be noticeable must come within 15 to 20 db. of the threshold noise: if it is less it is scarcely of account. Thus an office having a threshold level of 50 db. would not notice an intruding noise unless it were at least 50 − 15 = 35 db.; and if in that case intruding noises of 80 db. are to be defended against they must be reduced to at least 35 db., on the receiving side. They will require therefore a partition giving a reduction factor, at the appropriate pitch, of 80 − 35 = 45 db. This masking level is clearly of practical importance, because where high masking effects exist permanently as in an office building, or elsewhere, less efficient partitions are required. But masking cannot be relied upon if it is not a sustained noise.

The masking level generally found in rooms where conditions are moderately comfortable are as follows:

Recording Studios for speech	10–20 db.
" " " music	20–25 db.
Hotels, Flats, Houses .	20–30 db.
Hospitals	15–20 db.
Theatres, Churches, Schools	20–30 db.
Cinema Theatres . .	30–40 db.
Offices .	30–40 db.

Finally, the units we have been considering enable us to set a standard sound source when we measure and compare the reverberation time in seconds of one room with that of another. This standard is taken as 60 db. or approximately that of the speaking voice. We can then define the reverberation time of any room as the time in seconds that a sustained tone of any given pitch takes to decrease through 60 db. from the instant the source has ceased. Reverberation is discussed in detail in Chapter VI.

IV

CRITIQUE OF MODERN BUILDING TYPES

DURING THE last twenty years building types have changed: acoustic studies have contributed to this change: also new types have been added. What do the results show?

Council chambers have greatly improved: they are used for debate alone, they are brought under real criticism, money is readily granted for carpets and sound absorbents. New *law courts* are less fortunately found: but are now better defended from noise and more frequently reduced in respect of reverberation; but many old bad courts survive. *Committee rooms* are not nearly good enough: real care is not taken over them. But committee rooms are the brain cells of the community, and if they are generally hostile to hearing there must somewhere be loss of efficiency. There is a bad municipal custom of planning committee rooms *en suite* for receptions which means sliding doors, hardwood floors, and divided functions. Also panel-heating ceilings make more difficult the use of ceiling absorbents in committee rooms, classrooms, lecture theatres; yet it is in these humble auditories where everyday work is done that less reverberant and therefore less irritating conditions are badly needed.

New *theatres* have greatly improved in respect of hearing in rear seats and under galleries, yet serious complaints have shown themselves which we shall analyse. In *cinema theatre* design the acoustic engineers know what to do and have some successful buildings to their credit, but they are frustrated in the general ineptitude of speculative theatre building, and lack of critical standards in the cinema.[1]

In respect of *concert halls* progress has not kept pace

[1] In cinema theatres while the screen size for moderate grouping is *less* than the ordinary stage proscenium opening—which means in optics more remote—the loudness of voices is considerably *nearer* in its effects. Hence one of the many anomalous effects of screen 'art'.

with musical taste. London has not yet a hall equally good for first-rate choral as for first-rate orchestral music. In the inter-war period two fine old concert halls in the provinces have been spoiled for choral music by ignorant alterations by architects, and in another city a new hall has been built so poor for instruments as noticeably to handicap the musical activities of the city. We shall see also that the modern fan-shaped hall has real defects in respect of musical tone.

Churches have slightly improved but on no clear principles. Diocesan committees tend to live still in the era of the Gothic revival as far as acoustics are concerned, and do not realize that our problem to-day is to add an auditorium to a shrine. The pulpit is one of the few remaining *loci* of personality, and the preaching voice, unemasculated by mechanism, remains a means of direct communication of the Christian spirit. The voice shows the man. The shrine must remain the focus, but re-education in Christianity must also be by the intelligible word—by lesson and gospel and vital preaching. Since churches present a series of problems of their own—important from many aspects—a chapter is given to the subject.

Schools have been left empty, swept and garnished by the hygiene experts, so it is not surprising we find them occupied by the Seven Echoes.[1] But now many architects *wish to provide humane conditions*—a home for the mind: they have often to fight with their plans committees for the necessary small expenditure, but they think it worth while. Curtains, pictures, absorbing ceilings in classrooms: the hall treated with some absorption to make it tolerable for use as a classroom; floors silent underfoot; these things are recognized. I do not find, however, sufficient recognition of the function of the hall *stage* and its double use. (See p. 103.)

Technical Colleges in many ways are the failures of our time and need a new attitude on the part of designers if they

[1] Hygiene is made for man. It must be noted that children are provided with laboratory conditions in schools—hard floors, tiled dados, sirapite ceilings—but in the cinema are allowed to sit on carpets surrounded by upholstery and curtains. Also we know that with vacuum cleaning the cinema theatres are not in fact sources of infection.

are going to continue to perform even their technical function. (See p. 28.)

Of the *new types of building* the large exhibition hall, canteen hall, baths hall, relying on loudspeakers, cannot be described as successful; they present very difficult problems (p. 100). But the development of the music recording studio in the direction of good concert hall standards is significant. This is discussed in Chapter VIII.

CLASSIFICATION OF ACOUSTIC REQUIREMENTS

We can roughly classify auditorium design into that for speaking voice requirements, and that for musical requirements. In the first class come council chambers, committee rooms, law courts, etc.; in the second, concert halls, music studios, opera houses. Where acoustic conditions can be limited to one of the above sets of requirements acoustic design is straightforward. It is worth noting that, in the past, stringent limited requirements have in fact produced good acoustic buildings, by rule of thumb design; as, for instance, for music the German concert hall and Italian opera house, and for speech the English House of Commons. But to-day the tendency is to demand halls for all possible purposes. Then it is urgent to extract from building committees the chief requirement and put the others in order of importance. This applies to a large class of which town halls, assembly rooms, canteen halls, exhibition halls, etc., are examples.

V

DESIGNING FOR REFLECTION

RELATION BETWEEN RATE OF SPEECH AND BUILDING DIMENSION

LET US get a picture of what is happening when someone is speaking in a room. Public speaking proceeds at the rate roughly of 120 words a minute. That is 2 words or 4 or 5 syllables a second, and we must include in this the syllable intervals. Careful speakers go slower, players on the stage often go much faster: but we can take that speed of 120 words per minute—the efficient shorthand speed—as the average. A syllable then lasts for roughly $\frac{1}{5}$th second. It consists of a vowel which is a tone, initiated by a consonant which is an 'explosive' and gives the character to the vowel tone. The consonant part is much shorter than the vowel it characterizes, but we can think of speech as a series of $\frac{1}{5}$th second sounds, divided by a time interval, rapidly following each other. Now for articulation the time interval separating these sounds is as important as the sounds themselves: and this time interval is physiologically the shortest interval perceptible by the human ear, namely, roughly $\frac{1}{20}$th of a second. Speech then is a series of $\frac{1}{5}$th second syllables each preceded and followed by a time interval of $\frac{1}{20}$th of a second. The time interval is of course varied for effect, and in good reading the ends of sentences are marked by longer time intervals. The diagram (Fig. 8*a*) illustrates a sequence of four syllables.

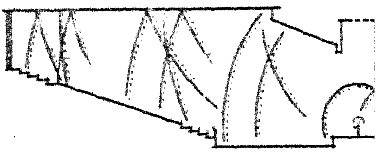


Fig 8*a*.—Syllables illustrated.

Again, these syllables go out in all directions from a speaker.[1] They are reflected by walls, ceiling, floor, etc. Therefore a listener is hearing not only the direct sound but, in addition, a number of reflected sounds. And if these sounds follow each other at *less* than one-twentieth of a second—the shortest perceptible time interval—they will obviously appear to sound together and will reinforce each other; but if the reflections should follow the direct sound by *more* than one-twentieth of a second, they will appear to prolong the sound; and if by much more, a repetition, or echo, may occur.

Now sound travels in air, at ordinary temperatures, at about 1130 feet per second. Therefore in one-twentieth of a second it will travel approximately 60 feet. Therefore if a reflection follows a direct sound along a path longer than 60 feet the shortest perceptible interval will be exceeded and sound will tend to be prolonged.

This then is the initial relationship between the time element of speech and the space element of building upon which a large part of building acoustics rests. (It was first enunciated by Guadet in his lectures on the Elements and Theory of Architecture at the Beaux Arts Schools in Paris.)

In well-designed halls only those reflections should be allowed which roughly coincide with, and reinforce, the direct sound. We should get then the impression of loudness plus distinctness. Every one knows on the other hand the case of the repetitive echo in large halls when the reflection arrives one-fifth of a second after the direct. But the most frequent damaging case is that which just closes up the one-twentieth of a second interval between syllables: *this often happens in rooms of moderate dimensions, like large committee rooms,* and can cause the extreme cases of unintelligibility. A short loud echo filling up the syllable interval is more dangerous than the faint long echo, easily drowned out by the direct sound.

In practice we often find that front side seats in very wide halls have a slight prolonging of sound due to reflections from front side walls; and we notice likewise that reflections

[1] A certain directing of sound energy is given by the human mouth but it is not nearly as great as the "directional effect" of horn loud-speakers.

from the rear wall—remote from speaker—may cause echo in front seats. This is illustrated in Fig. 9. Here two reflected rays of sound are shown, SK_1L and SK_2L : S is the speaker, L is the listener. Then SK_1L must not exceed SL by more than 60 ft. It is clear that the longer the room the longer will be the reflected path SK_2L and the greater danger of echo. It is for this reason that the 'west' walls of churches frequently cause trouble, and that it is a good principle always to render rear walls sound-absorbing, or diffusing, so as to reduce reflection.

It will be seen also that the nearer L is to S the greater geometrically is the excess of reflected over direct path. This means that front seats are more liable to echo than rear seats, and this is in fact the case, but on the other hand they are nearer the source and get greater loudness: but often when a speaker turns sideways and loudness falls off, then defects in near seats are experienced, and especially is this the case in front side seats in modern theatres.

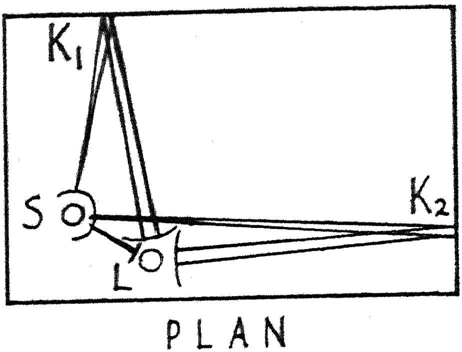


Fig. 9.—Excess Paths illustrated.

For the same reason high ceilings immediately over a speaker or preacher will cause prolonging in near seats, and it is owing to this that the tradition of the 'sounding board' in lofty churches has been developed and is of use: it cuts off a certain small amount of upward sound paths from pulpit: but is only of use in lofty churches. Another cause of echo is the remote ceiling angle in large halls, and from this has come the old concert hall tradition of ceiling coves or heavy cornices which serve to diffuse the sound. This is a thoroughly useful tradition.

The figure 60 ft. is, however, an ideal limiting value.

In large halls public speakers always tend to go slower and an excess of 70 ft. is permissible.

In music short echo is often perceived in rapid staccato passages and this is a defect in a hall. Concert halls should provide absolute articulation of rapid passages. It is possible to test for echoes in an empty hall by rapid sustained clapping of the hands. Short echoes can only be detected by very rapid clapping, but it is often possible to get the direction of an echo by that means.

GEOMETRY OF SOUND REFLECTIONS

It is worth testing plans of large buildings for echo by drawing out reflected paths, and the geometry of simple sound reflection is illustrated in Fig. 10. With sound, as with light, the angle of reflection is equal to the angle of incidence: therefore the source of sound has an image equidistant beyond each plane mirror. In Fig. 10 is shown the plotting of a beam of sound limited to a side panelling AB in a large hall, together with intermediate rays. Let S be the sound source. To find the image I produce BA to K. Draw SK at right angles to BK and produce SK to I, making KI equal to SK. Then I is the image of source S in mirror AB or AB produced. To find the limits of the sound beam from AB join IA and IB and produce these lines indefinitely. They will then give the boundaries of the beam extending across the room. Also lines drawn through intermediate points as A_1 and B_1 will give the 'rays' of sound reflected at those points. To illustrate the actual reflected paths join SA, SA_1, etc., and at each point of impact it will be found that angle of reflection is equal to angle of incidence.

The picture of a sound at a given instant, however, is not well represented by sound paths only. Since sound is propagated in all directions at equal speed, it must at a given instant have a circumferential wave front located at a corresponding distance from the source. And it is found that the direct sound and all reflected sounds have wave fronts related geometrically to each other and advancing at regular distances from each other. In this case (Fig. 10) take the lapse of one-fourteenth of a second or a path of 80 ft. from source. Then to find the direct wave front we

have merely to strike an arc ETF of 80 ft. radius from S as centre. And since sound travels at equal speeds in all directions the reflected wave front is got by striking an arc EL_1 of 80 ft. radius from image I as centre: and this

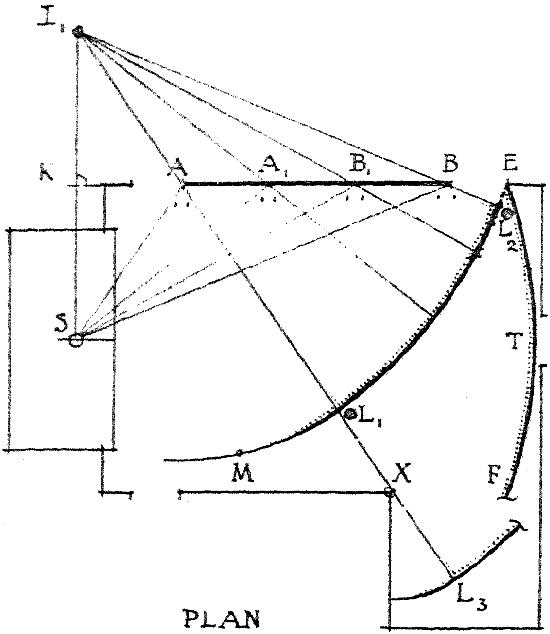


Fig. 10.—Diagram showing Plotting of Rays of Sound.

is merely to plot all reflected rays of a length equal to 80 ft. This relationship drawn out thus, of direct to reflected wave fronts, gives a proper picture of the sound; and it should be noted that first-reflected fronts always join direct fronts at bounding surfaces. Photographs of sound waves show this.[1]

[1] The waves can be seen on water in a bath by arranging a dripping tap. For a more elaborate plot, showing inter-reflections drawn out and compared to a sound wave photograph, see *Planning for Good Acoustics*, Figs. 44 and 45.

But since sound does not cast a sharp shadow like light but gives a penumbra, we must admit that the beam of sound from AB in Fig. 10 is not strictly limited by the line AL_1, and that a listener at a point M would in fact get some of the reflected sound. And the wave fronts as shown by [illegible] actually extend in the form of wave fringes as L_2M and this arc is not struck from I but from the edge of the mirror, namely A. Wave fringes can be shown on drawings by a diminishing or dotted line. The fact that sound *bends round* a corner, or more accurately that the wave fringe tends to spread round and fill up the gap caused by an obstacle, is the reason why we are often able to hear a sound source but not see it. This is illustrated also in the same figure by the wave fringe struck from the angle X and having radius XL_3 in the screened angle of the hall opposite.

Again it can be seen in Fig. 10 that at any point in the hall the direct wave front reaches a listener first followed by the reflection from side wall. And followed again, if we continued our analysis, by the reflection from wall behind source S. And here the law of the 60 ft. space interval can be stated in other terms: these wave fronts must follow each other within a space of 60 ft. if echo is to be avoided.

CURVED SURFACES

It is when long reflections are associated with concave walls, or ceilings, of long radius, that obstinate acoustic trouble arises. In a small council chamber known to me the two side walls were curved and struck from about the centre of the room (Fig. 11). These walls caused the concentration of sound so that reflections from them gave short echoes just filling up the one-twentieth of a second interval between syllables, and owing to concentration they were as loud as the direct sound. When the speaker had his back turned the reflections were louder. The concentrations are shown in the figure. (The speaker S is addressing the chair, and therefore has a number of members of council behind his back.) This concentration is a common defect and must be avoided in new buildings. Another lesson from this particular

building is that these curved walls had been at one time hung with curtains, but the improvement was negligible. The reason is that the close concentration of even a portion of the sound from such a curve is enough to cause trouble. For this reason also curved ceilings struck from head level or from floor level are a fruitful cause of trouble. Segmental and saucer domes are worse. The *locus classicus* is the Albert

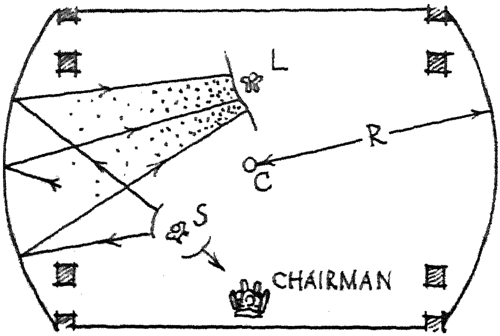


Fig. 11.—Case of a Council Chamber.

Hall, where concentrations of sound from domed ceiling arrive in arena seats at an excess path of some 200 ft., or after the lapse of one-fifth of a second, causing rapid music to be heard a beat late. Concave proscenium ceilings are also dangerous. But the modern curved rear wall to theatres and cinemas is the most fruitful cause of acoustic defects. Before carrying this further the geometry of reflection from curved surfaces must be summarized.

GEOMETRY OF CONCENTRATING AND DIFFUSING REFLECTIONS

In the case of curved surfaces a series of rays must be plotted each from a separate image, and then marked off equal in length from each image. This is illustrated in Fig. 12 in the case of a concave curve. S is the source of

sound. It is required to find the beam given by an arc AC forming a concave curve with centre O. Take three points —the limiting points A and C and one intermediate point B. Join SA, SB and SC. Also join OA, OB and OC and draw

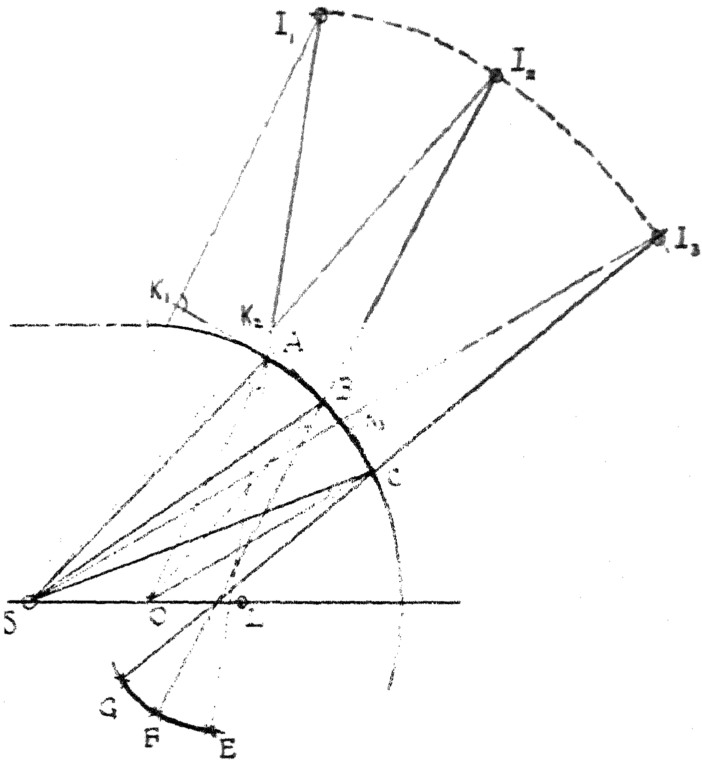


Fig. 12.—Plotting of Reflected Rays from a Concave Surface.

tangents AK_1, BK_2 and CK_3. Through S draw SK_1 at right angles to tangent AK_1 and produce to I_1 making K_1I_1 equal to SK_1. Then I_1 is the image for the single ray reflected at point A and the angle of reflection will be found equal to the angle of incidence. In the same manner find points I_2 and I_3 giving paths in the direction BF and CG. They will

all be found to converge on a restricted area near point L. And in circular buildings this area of concentration will always be found situated between the centre O and the circumference of the arc, and opposite to S the source. Beyond that area obviously the rays diverge. Further: to

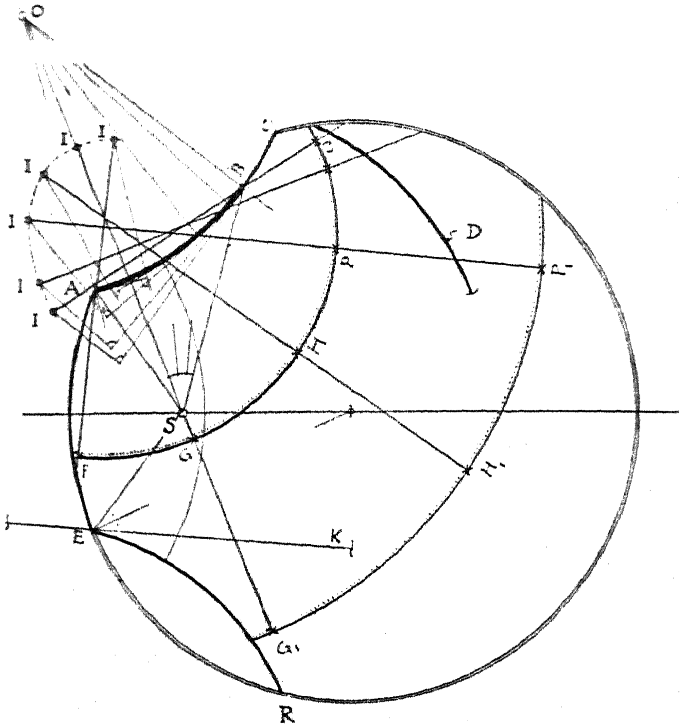


Fig. 13.—Plotting of Reflected Rays from a Convex Surface.

plot the wave front at a given instant calculate the distance travelled in the time and mark off from I_1, I_2, etc. equidistant points, giving this distance, along the respective rays: namely I_1E, I_2F and I_3G. The form of the wave front is given then by joining EFG. By taking further intermediate rays greater accuracy can be given to the plot.

It can be seen that since all the reflected sound falling on the curve ABC is concentrated in a very narrow area at L, if the reflected paths should exceed the direct, the echo will be marked. This effect is often found in certain seats in semi-circular buildings.

Convex curve reflections are plotted in an exactly similar manner, see Fig 13, but it will be seen that the concentrations occur beyond the mirror so that they are ' imaginary ', and the actual rays diverge widely. The sound falling from S on the convex curve AB in the figure is therefore not concentrated but *diffused*, and even if of long excess paths will not compete in loudness with the direct sound.

Therefore diffusing is one means to the prevention of echoes, and also to the distributing of reflected sound over a wide area in any auditorium. This means has been employed, in a rule of thumb manner, in old opera houses and concert halls, and is called the ' breaking up of sound '. It was the cause of the deliberate planning of columns, breaks, recesses, alcoves : it was also a reason of the success acoustically of the baroque theatre of the eighteenth century where plasterwork in the form of swags, cupids, cornucopiæ, relievos, shields, etc., did in effect prevent, by diffusion, serious echoes from the curved surfaces of large theatres, and gave conditions for the development of orchestral music as well as of the aria. Also in one recent broadcasting studio, cylinders were used, like columns down the sides, to diffuse sound ; and in another studio the walls were given a series of angular projections for the same reason.

Therefore we have two methods of counteracting the effects of sound reflection—(1) absorption by means of thick fabrics, carpets, upholstery etc. (to be referred to in detail in Chapter VI.), and also (2) diffusion.

AUDITORIUM DESIGN FROM REFLECTION

Let us apply the principles discussed above. By setting walls, and portions of walls, on the splay and thus multiplying near images, it will be found geometrically that a maximum of the reflected sound can be directed from the neighbourhood of the source to the neighbourhood of the audience. This applies of course only to halls and theatres where the

source is located upon a platform or focal area. And if this is developed it will be found that certain plans emerge as types of maximum reflection. Of these the most efficient is the parabolic plan in which the speaker is placed on a rostrum at the focus of the parabola. Next in efficiency come those pentametric plans which approximate most closely to the parabola by means of a number of plane

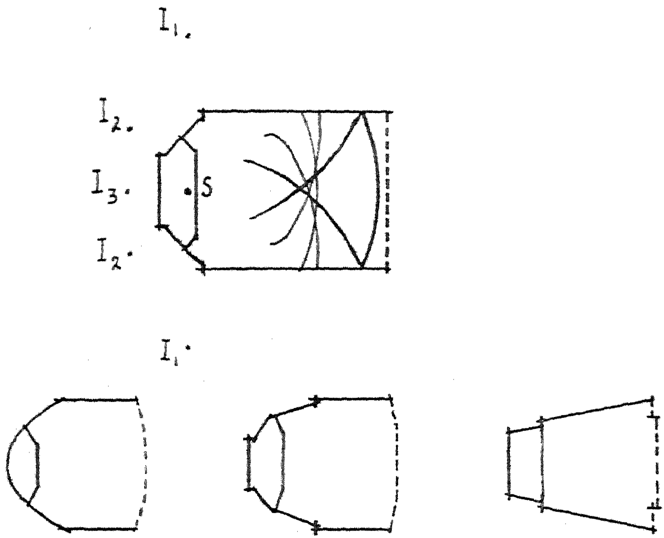


Fig. 14.—Plan Types giving Maximum Reflection.

surfaces set at an angle. This can be called roughly the 'megaphone type'. And finally comes the simpler fan-shaped plan. These types are illustrated in Fig. 14.

Now the parabola plan, perfect in theory, has a great disadvantage in practice. The total reflection is very powerful, but unless there is nearly 100 per cent. absorption at rear wall, small remainders of unabsorbed sound will find their way back to the focal area in the form of a noticeable echo. For this reason parabolic reflectors are successful in the open air, as in the Hollywood Bowl, where orchestral music is projected over a large open-air amphitheatre: and

the principle can be usefully applied for shell bandstands and open-air pulpits. But for the same reason they are not found successful in enclosed buildings. And this defect is also found to be disabling in the case of the megaphone type plans, of which the Salle Pleyel in Paris is an example, and also, to a less but still noticeable extent, in the case of the ordinary fan-shaped plans. The cause is a practical one. *It is found that it is easy to make a reflecting surface, with modern plasters, 98 per cent. reflecting: but it is not possible by ordinary treatments to make an absorbing surface more than 70 per cent. or 80 per cent. absorbing.* That is, there must remain under ordinary treatments some 20 per cent. to 30 per cent. of the unabsorbed sound reflected back and able to find its way to the front part of the house. And when the section reproduces the same outline character, the results are further emphasized. This is the principal cause of the defects in modern theatres referred to above, where complaints are always connected with seats in the fore part of the house. But there are other contributory causes.

In *Modern Theatres* the proscenium boxes have been swept away, plaster reliefs likewise, and a smooth hard continuous surface is the rule. Another and more powerful cause is the long radius concave curve of the rear wall. We must note that the fan-shaped plan provides better sighting than the old horse-shoe plans for theatres, and gives maximum gallery seating at a suitable distance from the stage. Therefore it has advantages not to be ignored. It is a modern type defective as it stands and waiting for the next step in experimental design.

The defects of this type on plan are illustrated in Fig. 15. The splayed proscenium, and sloping ceiling, are the main factors in directing the return sound back on to fore-stage and front seats. It is for this reason among others that many modern cinema theatres now treat proscenium areas with grilles, ribs, curtains, etc. Also in the same figure the slightly bunched reflections from curved rear walls are shown. It is remarkable in practice how slight a curve will give an echo back. This rear wall echo is specially dangerous from the pit under main gallery, which is a wall area often found on a level with the heads of actors. But the curved effects also extend to gallery fronts, to balustrades behind seats,

and total risers of seats. The risers of seats are not always carpeted and may amount to a large total area. In practice

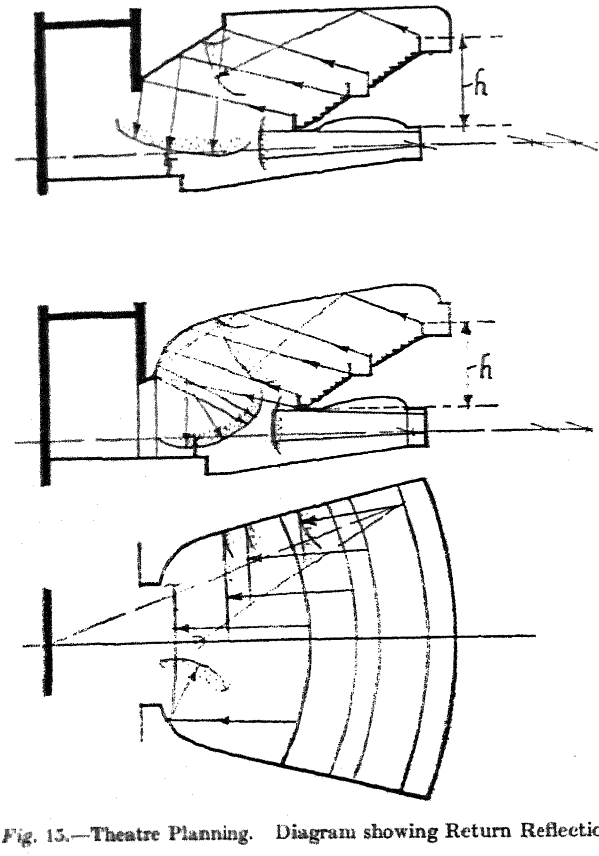


Fig. 15.—Theatre Planning. Diagram showing Return Reflections.

quite a considerable echo can find its way back from these curved elements, especially if flanked by smooth, hard-plastered side wall surfaces.

The remedies proposed are illustrated in Fig. 16. Side walls are broken up into a series of panels between projecting

ribs; the ceiling is made to form a series of steps offering breaks in the path of returning sound; proscenium (or platform) walls are made diffusing by convex surfaces; and rear wall is either stepped in plane surfaces or made markedly diffusing. Add also that gallery fronts, risers and balustrades are not curved but made polygonal; and that plinth walls to parterre are made in a series of convexities

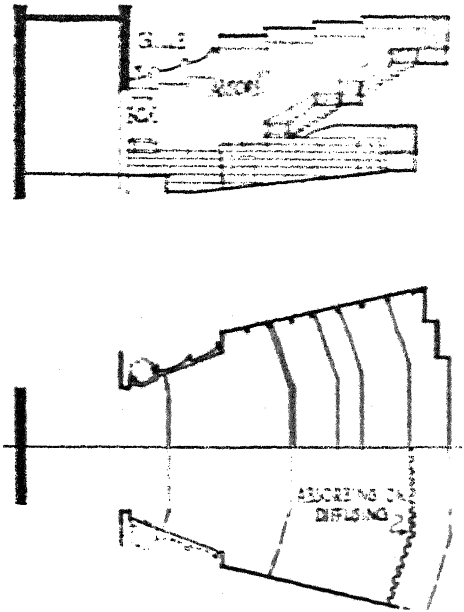


Fig. 16.—Theatre Planning. Design modified to avoid Defects.

or bolections. There is also shown an absorbing panel on *front side walls*. There is another reason for this. Inter-reflections, causing 'reverberation' in front seats (see p. 91), are often caused by hard wall areas in this part of a large auditorium, where there is no intercepting gallery. It will be seen therefore that a very necessary functionalism calls for the maintenance of the fan-shaped auditorium but with a splitting up of surfaces, and locating of diffusers—thus

providing a modern *design equivalent* for the heavy reliefs, boxes and drapery of the older types. It should be noted

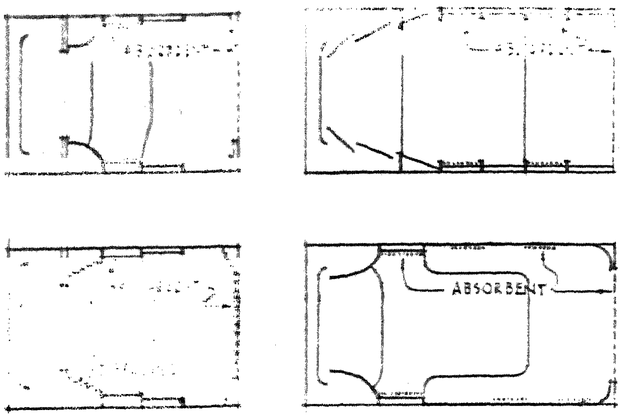


Fig. 16*a*.—Auditorium Planning. Modified Designs.

also that the panel areas on walls allow of the application of the modern theory of distributed rather than concentrated absorption which we shall discuss later (p. 113). Modified plans for modern halls are illustrated in Fig. 16*a*.

BEHAVIOUR OF CEILINGS

Since ceilings are powerful reflectors we must here briefly note the action of different types. They are illustrated in Fig. 16*b*. The reflections for each are shown plotted for a source *s* : where ceilings are curved the centre of curvature *c* is shown. The *flat ceiling* (1) distributes sound over floor and part walls no matter what the position of *s*. The *barrel* (2) reflects through a focal area between centre and circumference, that is to say, at a high level, and then diverges over floor. It tends to give local reverberation, and in high gallery seats unequal concentrations of sound. The *segmental* or radial curve (3) struck from head level, is shown concentrating sharply on to the floor area : this ceiling is associated with acoustic complaints more than any other. Also when the source moves from centre the

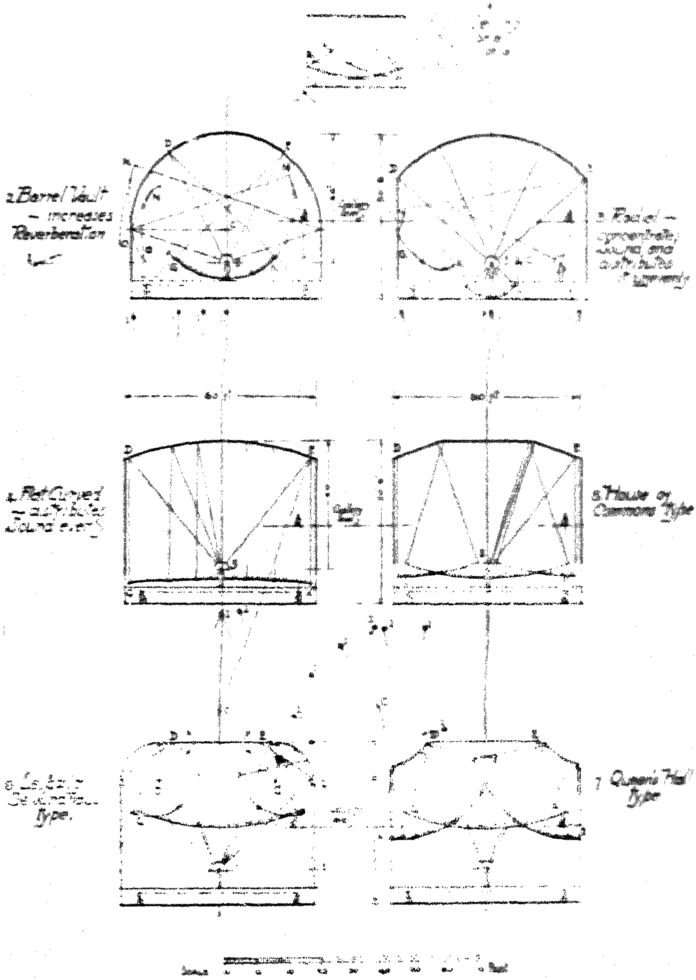


Fig. 166.—Behaviour of Ceilings.

area of concentration swings over in an opposite direction. This explains why so often under ceilings of this kind it is difficult to hear a player on the same side. A radial ceiling with much longer radius is shown in (4): this is less dangerous. In (5), (6) and (7) are shown three satisfactory types of ceilings derived from actual buildings.

OPEN-AIR AUDITORIES

We can design, from reflection data only (ignoring reverberation), a few types of buildings having the characteristics of open-air auditories. Open-air theatres are the characteristic example.

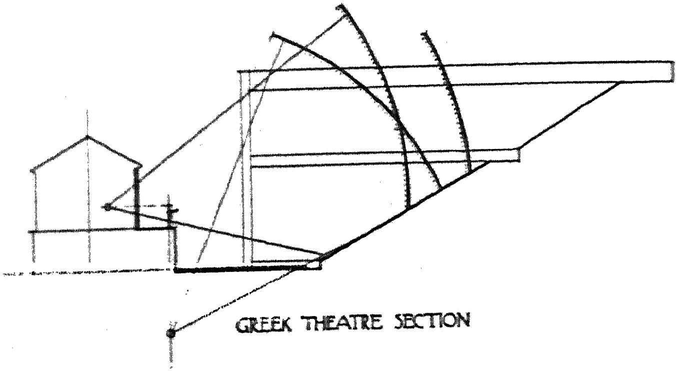


Fig. 17.—Greek Theatre Reflections.

The secret of the good acoustics of the *Greek theatre* was that a few factors combined towards a single end. The players had a back wall reflector not far behind them, and also had a hard paved 'orchestra floor' below them acting also as a powerful reflector. These two reflected sounds followed closely upon the direct (Fig. 17). In the Greek theatre also, owing to the rake of the seats, direct sound reached heads of audience at an efficient angle. Lastly there was no roof and consequently no reverberation.

The value of the floor, deliberately used as a reflector, has proved itself in modern design. A hard uncovered floor area of some 6 to 10 ft. deep is valuable in concert halls in front of the platform to increase tone (see also council chambers

p. 98). But the principle must be applied with discretion in those cases where there is risk of serious inter-reflection between floor and ceiling, with consequent risk of local reverberation.

Bandstands can be much more effective if reflecting surfaces are deliberately designed. In the circular type the roof ought to be slightly convex and extend as far out beyond the floor, pagoda fashion, as possible. But also a hard-paved

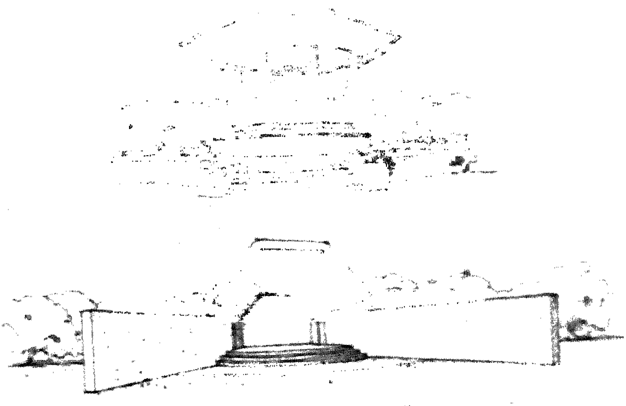


Fig. 17a.—Sketches of Reflector Designs for Bandstands.

floor reflector, kept clear of seats, all round the circumference, is highly desirable. A teak deck floor, rail and windscreens must also be envisaged.

Shell Bandstands require a reflector in solid structure, giving sides and hood at an efficient reflecting angle. Wing walls can also be placed effectively. The hood should project well out. In addition an uncovered hard-paved area in front of the platform should form part of the design. A strip of ornamental water has been used effectively for this purpose. The selection of the site to give a good natural amphitheatre and rake for seats is essential. A quiet locality must be chosen. Since shell bandstands are often used for concert parties a dressing-room, and loudspeaker equipment, should be provided. Sketches illustrating points are given in Fig. 17a.

VI

DESIGNING FOR REVERBERATION

WE HAVE hitherto considered, under echo, a single reflection from a local surface lasting for the fraction of a second. Reverberation is the result of prolonged inter-reflection from a number of surfaces and may last for several seconds. Reverberation therefore may cause greater confusion and overlapping of sounds than isolated echo. Organists speak of the reverberation of St. Paul's as 12 seconds, York Minster 10 seconds, and they mean by this the duration of the sound after the hands are lifted from a full chord on the great organ. We have there a very rough means of comparing the sound energy in different buildings. If we take an accurate standard of loudness more nearly that of ordinary uses, and measure in fractions of a second, we can apply this method to ordinary buildings. We have seen in a previous chapter that the standard chosen is roughly that of the speaking voice or the equivalent loudness of 60 phons (p. 65). Also we noted that the reverberation time in seconds is the time taken for a source of 60 phons to die away to the minimum audible; or in terms of energy for a sound of 60 decibels to decrease to threshold intensity.

Now the sound dies away gradually[1] by the absorption of energy at each contact with walls, floor or ceiling. Therefore the fewer the contacts in a given time the less the absorption and the longer the reverberation. But the larger the building the fewer the contacts in a given time; and therefore the larger the building the longer the reverberation, or: t (time in seconds) varies directly as the volume V. Also the more absorbing the bounding surfaces of the room the more energy is subtracted at each contact and therefore

[1] This is an empirical assumption and is not exactly the case as we shall discuss later: see footnote, p. 93.

the shorter the reverberation, or: t varies inversely as the total absorption A. That is to say, t varies as $\frac{V}{A}$ or:

$$t = \frac{V}{A} \times \text{a constant } k.$$

The fact of reverberation was recognized by Reid and by Rayleigh, but it was W. C. Sabine of Harvard who first achieved time measurements of reverberation in different rooms in order to analyse the variables, and it was he who formulated the relationship.[1] The constant k is a physical ratio holding good for ordinary rooms and materials as between volume and reverberation and total absorption; and this ratio was found to be:

$$t \text{ seconds} = \frac{1}{A} \times 0{\cdot}05 \text{ V (foot units)}$$

$$= \frac{1}{A} \times 0{\cdot}164 \text{ V (metre units)}.$$

To find the total absorption A in the Sabine formula it is necessary to measure the surface area of each material constituting bounding surfaces, furnishings and occupants, and multiply each area by its appropriate percentage absorption or by the coefficient equivalent to that percentage; in other words

$$\text{A (total absorption)} = a_1 s_1 + a_2 s_2 + a_3 s_3, \text{ etc.},$$

where s_1, s_2, etc., are the various separate surfaces, and a_1, a_2, etc., their appropriate coefficients.

Thus it is found that if 1 sq. ft. of open window absorbs 100 per cent. of the sound falling upon it at middle pitch, then hard plaster absorbs approximately 2 to 3 per cent.; a boarded floor, 4 per cent.; carpets, 20 to 30 per cent.; wood panelling, 6 to 10 per cent.; an audience, 70 to 80 per cent., or approximately 4 units per person.

Now these rough figures show at once how large a proportion of sound is absorbed by an audience, and therefore why it is that the audience factor in bare halls causes such variations in the acoustic conditions. In addition to the

[1] W. C. Sabine, *Collected Papers in Acoustics*, Harvard Univ. Press. An account of Sabine's experiments and the development of his formula is given in *Planning for Good Acoustics*, Ch. II.

audience factor, upholstered seats, carpets and drapery play an important part, and it is necessary to bear in mind these major factors in calculating desirable reverberation. Where carpets and upholstered seats are present, as in cinema theatres, the audience factor is *less* important. In churches, halls, lecture theatres it is *more* important. Also the audience factor is liable to be small in some types of building and large in others. *Therefore desirable reverberation figures ought to be stated in reference to the significant audience factor.* In practical acoustic design they can be summarized as follows:

Type of Building.	t by Sabine Formula.	Audience Factor.
Law courts, conference and committee rooms	1 to 1·5 sec. varying with size of room.	One-third audience.
Parliament houses, council chambers	1 to 1·5 sec.	Quorum.
Board rooms . .	1 to 1·3 sec.	3 persons.
Halls and auditories for public speaking	1·5 to 2 sec.	One-third audience.
Concert halls . .	1·6 to 2 sec.	Full audience.
Theatres and cinemas .	1·3 sec.	Two-thirds audience.
Churches . . .	1·8 to 3 sec.	Two-third congregation.
Very large halls . .	2 to 3 sec.	Two-thirds audience.

In the table given above the reverberation is often given to limiting values, as 1 to 1·5 seconds: and in fact it varies with the variation in volume. This applies specially when very large dimensions are encountered. In a very large hall a public speaker naturally goes more deliberately, and a perceptibly longer reverberation is permissible. Also in very large halls if an excessive absorbing area is introduced in an attempt to keep down reverberation the loudness will be reduced too much.

In *council chambers, law courts, board rooms*, note that

the audience factor may often be very small indeed: so that a large area of added absorption is necessary. Board rooms may often be large yet only three persons present. Law courts often have few people present [illegible] no carpets to help the total absorption. *Concert halls*, on the other hand need a perceptible reveberation for good musical tone and the critical audience factor occurs with hall full and therefore reverberation at minimum. Obviously acoustic design must aim at preventing complaints at the critical condition.

It is useful in preliminary calculations to note the *cube per seat*, because, where the audience factor is significant, cube per seat gives a relationship of volume to absorption and is therefore a very rough index to reverberation. In planning, it is the height of a hall that can vary the volume and vary, therefore, the cube per seat, so that at the sketch stage there is some control of reverberation conditions. A reason for the general complaints caused by domes and barrel vaults is that semi-circular shapes give the minimum surface for a given volume. Where there is great height and therefore a large cube per seat a proportionately greater amount of added absorbents on walls, ceiling, etc., will be required. Conversely, if a concert hall is cut down in height, reverberation, with hall full, may be insufficient.

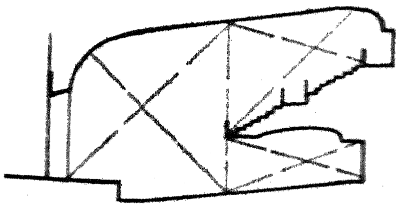


Fig. 18.—Theatre Section indicating Cube per Seat in different Parts of the House.

A useful example of comparing types by cube per seat is shown in the fact that a good concert hall ought to have more than 200 cubic feet per seat, and a theatre considerably less.

In the case of *large theatres* the reverberation figure of 1·3 seconds, when calculated in advance from plans and specifications, remains an average and is not true of every position in the auditorium. A glance at a theatre section will show why: the cube per seat in the front of the house, in an ordinary commercial theatre, is large; the cube per seat in the galleries is small (Fig. 18), so that the reverbera-

tion 1·3 seconds—derived from the right *average* relationship of absorption to volume—is in effect 1·4 or 1·5 seconds in the front of the house; and 1·2 seconds in the galleries. This is a contributory cause of the complaints made in respect of modern theatres (referred to in Chapter V.) which always occur in the front of the house. It can be overcome by placing a large panel of sound-absorbing material on front side walls as illustrated in Fig. 16. It must be noted that this principle applies to all halls of the fan-shape or megaphone type. In addition, large theatres having hard plaster proscenium, without the old types of curtains, pelmet, stage boxes and heavy ornament can have a local reverberation arising from inter-reflection between fore-stage and proscenium ceiling and walls. Also the very large type of modern stage can easily give stage reverberation when the set is simple and unenclosed.

In the case of *churches*, the cube per seat is very large indeed, the congregation often small, therefore reverberation always tends to be excessive, and modern design must en-[illegible] treatment. (See Chapter X.)

The Sabine formula is a means of applying a rough standard, by calculation in advance of construction. It is not exact. In *recording studios*, and in highly absorbent or 'dead' rooms generally, it is found that reverberation calculated by the Sabine formula gives reverberation times higher than is found by actual test. That is to say, the total absorption A given by the theory is not quite enough. To give a truer value to absorption under these conditions, C. F. Eyring [1] has modified the Sabine formula to:

$$t = \frac{\cdot 05\ V}{S\ \log_e(1-a)}$$

where S is the total surface area in the room and a is the *average* coefficient of absorption got by dividing total area S by total absorption A. In rough calculations it is sufficient to subtract about 0·2 seconds from the Sabine figure in the case of moderately absorbent rooms of volume round about 100,000 cu. ft. As the relative absorption increases,

[1] Eyring, C. F., 'Reverberation Time in Dead Rooms', *Journal Acous. Soc. of America*, January 1930.

as in very dead rooms, a [illegible] of 0·3 to 0·5 is found.[1]

EXAMPLE OF CALCULATION

A moderate-sized hall used for general purposes seats 600 and has a volume of 120,000 cu. ft. Since it is often to be used with small audiences the reverberation aimed at is 1·6 seconds with one-third audience. It is required to find from the plans the amount of added absorption that will be necessary. Indications of furnishings and finishings have been given.

The total theoretical absorption required from the Sabine formula then taking t at 1·6 seconds is

$$A = \frac{V}{t} \times 0{\cdot}05 = 3750 \text{ units.}$$

The cube per seat is 200 cu. ft. so that even with a full audience a fair amount of added absorption would be required, and therefore a greater amount with one-third audience. Let us determine, therefore, upon a large panel of sound-absorbing material on rear wall, and include this in an analysis of the contributory factors in the hall from the plans and notes. This is necessary in order to ascertain how much absorption will be given in practice by the ordinary conditions. It is convenient to set out the various factors as in table overleaf.

[1] A clear account of this is given by H. J. Sabine in an article written for the Journal of the Acousti-Celotex Co. in August 1934, as follows: 'The Sabine formula was derived on the assumption that sound energy along any given path in a room dies out in a continuous manner, whereas the general formula (Eyring's) takes account of the fact that the decay of sound energy [illegible] takes place in small consecutive steps, each step occurring as the sound strikes the surfaces of the room and is partly absorbed and partly reflected. It is shown that on the latter basis sound energy dies out more rapidly than if a continuous decay is assumed.' An approximation to Eyring's formula can be written thus: $t = \frac{{\cdot}05\ V}{A} - {\cdot}027\frac{V}{S}$ where S and A have the connotation given above. This interprets the Eyring formula as giving reverberation time by the older formula minus a correction factor ${\cdot}027\ \frac{V}{S}$. The percentage difference between the values given by the two formulæ increases with the increase in the total absorption and decrease in reverberation.

Vol. 120,000 cu. ft. Total seating (audience) 600. Cube per seat 200 cu. ft.

Absorbent Factor.	Area in sq. ft. or Number.	Coeff.	A (open window units).	Adjustment.	Net A (O.W.U.).
Hard plaster on [illegible] lite, etc.	7400	0·02	148		148
Wood dado, doors, etc.	7000	0·06	420	[illegible] for resonance).	420
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Curtains, thin, in folds.	700	0·2	140		140
Wood block floor.	1750	[illegible]	190	Less 20% for shading.	152
[illegible] felt mat.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Special absorbent on rear wall, canvas over felt.	700	0·6	420		420
Seats well upholstered at 2 units per seat.	600	2 units per seat.	1200		1200
	Then Total of Absorption contributed			.	2741
[illegible] less 2 units for occupied seat.	[illegible]	[illegible] = 2	1200		1200
One-third audience.	200	2	400		[illegible]

We see from the upper portion of the above table that the ordinary conditions of the hall complete with carpet on gallery, curtains, necessary rear wall absorbent and well-upholstered seats, will contribute 2741 units. Add to this the contribution of the significant audience factor, namely one-third audience,[1] which gives another 400 units. Total contribution is then 2741 + 400 = 3141 units. The balance

[1] But remembering to subtract for portion of seats covered by that number of audience. This is best done as shown in the table by using a *remainder coefficient* for the audience factor, that is a figure got by subtracting coefficient per seat from coefficient per person, in other words excess of person over seat.

required therefore to make up the necessary 3750 units is $3750-3141=609$ units.

Now these units can be provided either by a further area of an absorbent like the canvas over felt already used on the rear wall; or can be a special perforated tile on a part of the ceiling: or by any suitable method, or combination of methods. Let us decide on further wall panels of canvas over felt, having coefficient 0·6. To convert units of absorption into equivalent areas divide by the coefficient. In the case given, the necessary 609 units at $0{\cdot}6=\frac{609}{0{\cdot}6}=1015$ sq. ft. This area must then be distributed round the side walls between dado and ceiling, and may occupy the major part.

It should be noted in practice that school halls, used often for classrooms, are of the type just analysed. They usually have bare floor, and seats not often upholstered, so that quite a large area of special absorbent requires to be added and may occupy total wall area between windows together with a considerable ceiling panel.

Turning again to the analytical table, it will be seen that the third-column figure is obtained by multiplying the figure for area in the first column by the coefficient in the second column. There is a fourth column for 'adjustment' in which any additions or subtractions to meet a particular case can be made. In addition to those shown, it should be noted that where the walls of the room have multiplied mouldings, breaks, recesses, it is useful to add 5 per cent. to 10 per cent. for the contribution made by areas of hard plaster measured on the flat. In the case of the special absorbent which covers up the hard plaster behind, it is right in theory to use a remainder coefficient, that is, to subtract the coefficient for the plaster: in this case $0{\cdot}6-0{\cdot}02=0{\cdot}58$. In practice the difference is so small it is not worth while.

SOUND ABSORPTION COEFFICIENTS

Figures for absorption coefficients are approximate only.[1] They vary with the methods of test in different laboratories.

[1] Experience acquired in the use of large areas of special absorbents in recording studios has called in question the commonly accepted value of these absorbents as given by laboratory tests in highly reflecting

with the methods of fixing and mounting on the job, and particularly with the methods of decoration used.

In addition coefficients vary with the pitch of the sound. But for ordinary calculations, coefficients at middle pitch 500 to 512 cycles are used. It is found convenient to give figures for isolated objects such as members of audience, and seats, in the form of coefficient per person or per seat. On the opposite page is a list covering those usually required in acoustic design for [illegible] conditions.

It should be noted that absorbents such as the asbestos spray, muslin-covered felt, and acoustic tiles and plaster of the pumice variety can be totally spoilt as to absorbing power, if the decorator is given a free hand on the building after the treatments have been installed. Decoration of absorbents must be considered as part of the acoustic treatment and only done under proper supervision. The porous tiles and plaster cannot be brought to a sharp arris but need rounded external angles, or to be placed in shallow recesses. It is advisable to take and carry out the advice of the manufacturers. If laid in two coats the first coat must be given time to dry out before final coat is applied. The quilts and building blankets are generally mounted on battens 20 in. apart, and their fabric covering requires careful upholstering and stopping against a mould at margins. The 'woodwool' type boards or slabs can be distempered without loss of efficiency, which is an advantage, but will not show light clean colours. Owing to uneven condensation absorbent surfaces will not long retain the same colour as plaster walls or ceiling, and are best decorated in a contrast. Also 'breathing' through absorbent fabrics on ceilings or over vents in walls will soon show dirt: they should be placed on properly sealed surfaces.

test chambers. See Messrs. Norris and Nixon of the National Broadcasting Company of America (*Jour. of Acous. Soc. Amer.*, 1935, p. 239). Dr. Paul Sabine gives an explanation of the relatively high values obtained in reverberation chamber tests as follows: 'The presence of a localized highly absorbent area in an otherwise highly reflecting room (as occurs in a test chamber) makes the flow of energy towards the absorbent area on the average greater than towards an equally highly reflecting area, and this disproportion is greater the higher the intrinsic absorptivity, and the smaller the ratio of the area of the absorbent surface to the total superficial area of the room.' (Paper published in Report of London Congress of International Society for Testing Materials, 1937, entitled 'Present Status of the Measurement of the Sound Absorption Coefficients.')

LIST OF ABSORPTION COEFFICIENTS

Absorbent.	Coeff. for 500 to 512 cycles (ft. units).
Open window .	1·0
Brick wall : painted	·02
Ditto : unpainted .	·03 to ·05
Plaster : gypsum or lime, smooth finish on brick or tile .	·025
Ditto : on lath .	·03
Plaster : rough finish undistempered on lath . . .	·04
Glass . . .	·03
Marble or hard tile or glazed brick . .	·01
Wood panelling .	·06 to ·1
Floor : concrete .	·015
Floor : wood block .	·06
Floor : lino, rubber or cork, on the solid	·03 to ·06
Carpet : unlined .	·15 to ·20
Carpet : on felt .	·20 to ·35
Curtains : light .	·1
Curtains : medium .	·15
Curtains : heavy in folds . . .	·2 to ·5
Stage opening depending on drapes	·25 to ·5
Deep balcony opening with upholstered seats . . .	·25 to ·8
Grilles . . .	·15 to ·5
Fibre boards : ½ in. thick undistempered	·2 to ·3
Special Absorbents.	
Acoustic porous plasters : [illegible] in. thick natural colour .	·25
Acoustic porous tiles 1 in. thick natural colour . . .	·4
Acoustic felt ½ in. with decorated and perforated fabric cover . . .	·65 to ·75

Absorbent.	Coeff. for 500 to 512 cycles (ft. units).
Acousti-Celotex tiles decorated with perforations exposed .	·35 to ·7
'Sanacoustic' type tile perforated . .	·85
Asbestos spray : according to thickness	·35 to ·7
Double quilt or felt, and canvas on battens . . .	·7
'Woodwool' type tile 1 in. thick .	·6
Ditto : board ½ in. thick . . .	·4
Leather over felt on a wall board .	·35
Glass silk or slag wool 2 in. thick .	·85
Coefficients per Object	***Foot Units.***
Audience, per person	4·0
Plywood or ash chairs . . .	·2
[illegible] length . . .	·4
Theatre chair : leatherette upholstered . . .	1·6
Ditto : plush upholstered . .	2·6
Coefficient per Object	[illegible]
Audience per person	0·44
Ash chairs . .	0·016
Cushions :	
felt covered .	0·19
Theatre seats :	
ply-wood, no upholstery . .	0·02
imitation leather .	0·15
velour upholstered	0·25
Audience per sq. metre or sq. ft., ordinary seating .	0·98

VII

SOME BUILDING TYPES AND THEIR REQUIREMENTS

WE ARE now in a position to note shortly the design points for a number of different building types considering both reflection and reverberation factors. There is first the class of buildings having requirements for the speaking voice only.

Council chambers must be planned on the quiet side of the site. They need a flat or slightly recessed ceiling to give a reflecting surface normal to all seats. The ceiling may include a lay light. Floor must be carpeted and seats upholstered to give permanent absorption for large or small attendances of members and to give quiet gangways. In large chambers, however, loudness can be noticeably improved for front bench members, officers, chairmen of committees, etc., by omitting the carpet over the portion in front of the president's rostrum and having a hardwood floor finish. This then gives some floor reflections. The corresponding area in the ceiling vertically above ought then to be made absorbent to prevent a local reverberation. But even with thick carpeting and upholstery it will still be found necessary to add large areas of wall absorbents above dado height and it is usual to allow for this between all windows. A tapestry or good fabric over a quilt or felt is generally preferred for the sake of its finish. Acoustic tiles can be used. An important requirement also is accommodation for the press near the front, or front sides, or in front row of public gallery. Also the smooth working of the chamber is greatly increased if permanent officials are provided with seats just to the rear of, or in front of, the chairmen of committees, so that consultations can be made during a debate. Quiet floor finishes to galleries and lobbies, quiet swinging doors, silent-running ventilator fans, are essentials. The plans of two successful chambers are given in Fig. 18*a*. Hertford County Hall Chamber is by Messrs. James and Pierce, Wandsworth Town Hall by Messrs. William and Edward Hunt.

Law courts must be planned on the quiet side of the site or else be designed with small clerestory windows, kept shut, and a lay light. Floors quiet underfoot, such as wood block or lino or rubber, on the solid, are essential, and this applies to lobbies and galleries. Ceiling must not be curved but flat or stepped to give normal reflections. The walls above a hardwood dado must allow of large areas of some hygienic absorbent such as the perforated tiles or else an acoustic tile of the pumice variety. Alternatively, absorbent material can be distributed over walls and ceiling. In large courts the witness box is better placed for hearing between the jury

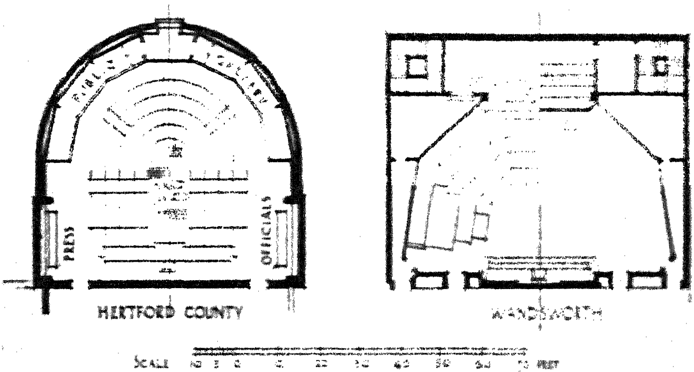


Fig. 18*a*.—Council Chamber Plans.

and the bench so that jury and magistrates or judge can get a profile view of witness: some judges however object to this.

Board rooms and *committee rooms* have already been noticed: they require close carpeting and a large area of wall absorbent. Segmental ceilings have been found to give inter-reflection between ceiling and hardwood table top and are best avoided. Flat or coffered ceilings are desirable, and a table cloth is an advantage. Defence against traffic noise by planning on the quiet side is important: if located on the noisy side then closed heavy windows and some intermittent ventilation (see page 51) should be employed, or better still air-conditioning. Designing committee rooms to open *en suite* for assembly purposes does not make for efficiency.

Where a high finish to the room is intended, then a fabric or one of the muslin-covered felts distempered and pricked is a suitable absorbent. Otherwise the perforated tiles or asbestos spray can be used on the ceiling.

When we come to the class of auditories used for all possible purposes the problems are more difficult.

Canteen halls in factories are now often of great size. Requirements include dancing, theatricals, music of all kinds and cinema shows. The stage must therefore provide proper theatrical accommodation with ample wing space and scenery dock and workshop with bench. For stage accommodation see notes on school stages below. But in large works musical requirements will be found quite as important, and for this the vital principle applies of providing an ample fore-stage, say 7 ft. deep, on which strings and wood-wind can sit in front of and not behind the proscenium arch. In large halls this is equally important for dance bands and concert parties. This means two troughs for footlights but the slight extra outlay is well worth while. A concert party in an [illegible] ft. canteen hall will not get its jokes and patter across if lost behind a proscenium. A dance band can sit wholly on the fore-stage and have a wooden screen placed behind them. Also good footlight microphones are wanted and a properly designed loudspeaker system. A good method is to have a row—at least four—in the proscenium surround, immediately overhead. Also there should be a forward position in the ceiling of the hall for spotlights and some means of switching on and off the main lighting of the auditorium from the stage. A boarded floor for dancing need not extend over the whole area but occupy a large central space with the surrounding margins of a floor finish, silent underfoot, such as wood block, or lino, or rubber on the solid. Loudspeakers should be connected with a gramophone having two turntables in a small room off the floor where dance records can be played and stored. A screen to the bar and refreshment hatches is desirable. Since a good canteen hall can be the centre of the social life of the factory, care and foresight should be exercised upon its design. For further information see the publication *Canteens in Industry* (published by the Industrial Welfare Society, 14 Hobart Place, S.W.1, 1941, price 1s. 6d.).

In *municipal halls* the points to note are: that halls must be separated on plan in order to let separately, and must on no account intercommunicate: that the larger be designed as a concert hall with choir staging and *without a proscenium* but with a good loudspeaker system for public meetings: that if a large hall only is provided, then the platform is liable to be draped with curtains to give a music-hall stage and by that means conditions for good instrumental music are spoiled: that a smaller hall be designed as a hall theatre (that is, with level floor) and cinema, but with a fore-stage. The *fore-stage* is essential for chamber music, for dance bands, for concert parties, for lectures and demonstrations. The stage must not be cramped as to proscenium [1] width and should have proper wing space, a scenery dock and theatrical workshop with bench where knocking-up of scenery can go on every evening but not disturb others, and also wardrobe space and dressing rooms. The entertainment manager at Wolverhampton told me, before the war, that their small hall was let for amateur shows (including rehearsal) every night and that rehearsals presented problems. The small hall is also useful for afternoon trade cinema shows with teas served. The absorbent treatment is most important: a gallery on rear wall is desirable, and the rear wall, part side walls, and part [illegible] sound-absorbing treatment: the reverberation figure must be brought down to 1·2 or 1·3 seconds (Sabine formula) for a hall theatre seating 500 to 700 persons. If it is up to 1·5 or 1·6 seconds, amateur players (and professionals also) will not make themselves well heard. Suitable absorbents are the paintable tiles, fabric over quilt, acoustic felt screened and pricked. Acoustic plasters and tiles of the porous variety are not serviceable where music is a requirement, owing to selective absorption.

Exhibition halls need bold fundamental design embodying auditorium extension and contraction; flying wood screening to put as reflectors behind orchestras when

[1] How well amateurs know the [illegible] ideas that comes from acting in the [illegible] art impossible. Therefore give maximum [illegible] depth of 20 ft. with ample wings. All art [illegible] and might grow out of it again.

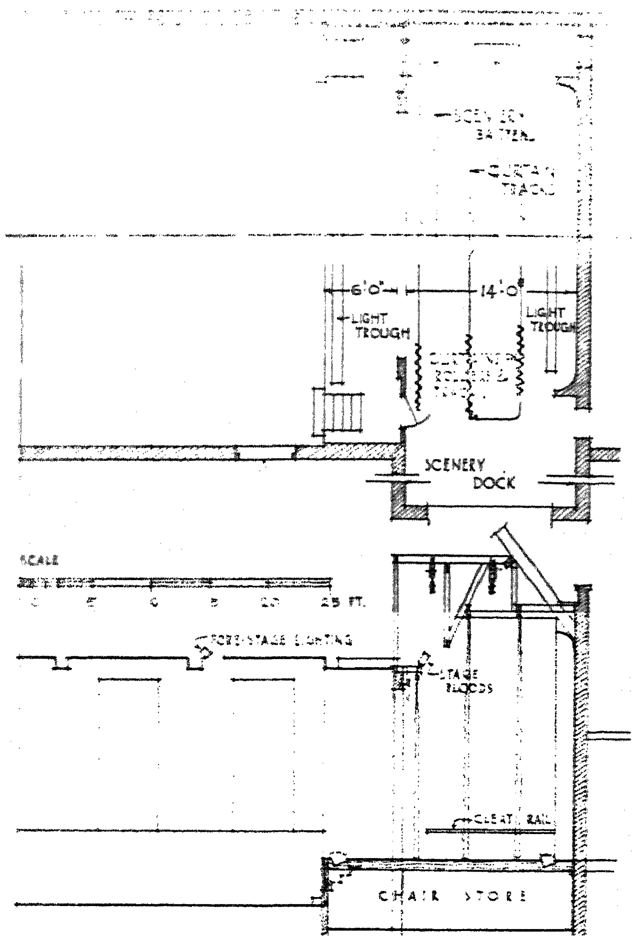


Fig. 19.—Minimum Requirements for School Stages.

required ; movable choir staging ; the right place for organ ; pageant entries and exits ; skeleton proscenium ; special rostra at a high level for dance bands ; boxing platform ;

also plenty of storage space for these movables when not in use. Also a well-thought-out loudspeaker system is required. The latter is difficult. If there is a main permanent staging, then one method is to group loudspeakers vertically above on a batten or behind a series of grilles in the proscenium surround: there must be a number overhead, rather than one loud one on each side. The dance band will require its own amplification system having microphones in the dance band rostrum. Loudspeakers must be switched in separate groups so as to be used separately in different parts of the building.

School and college halls. Here the problem is to provide a simple but adequate stage at one end and extensible or convertible gallery at the other. School halls have to act as classrooms, dining halls, as assembly for 300 at lectures, but for 600 or 700 for speech days, for school plays, school concerts. In senior schools and village colleges the halls may be let to clubs and [illegible] for dances. The windows must be easily darkened and good curtains envisaged and made part of the decorative scheme—not left to chance. It is not necessary to provide a fire-proof projector room if non-flam films only are used. The gallery is actually often used as a separate classroom under war-time conditions and the principle of a larger, or classroom, gallery could be used to provide the extra accommodation for plays and concerts. An adjustable curtain or absorbent partition would be required to cut off such a gallery. Sound absorbents are wanted at rear and this partition curtain would either act as an absorbent itself or, pulled back, reveal a large full gallery acting as an absorbent. But side walls and part ceiling will also need absorbent treatment. One of the hygienic paintable tiles or woodwool type board (Thermacoust) is suitable. The following notes on stage requirements for schools are drawn up from the practical experience of masters and producers in schools.[1] They refer with equal force to college halls. They are illustrated in Fig. 19.

[1] The reason why architects must now envisage [illegible] school stage and not rest content with the hutch platform, is because the teaching of English has now replaced the classics as a means to culture, and boys can be taught their own language, and taught to speak audibly, by stage plays. Also art can be taught [illegible] and in, the theatrical handicraft shop. [illegible] notes embody not fads but vital requirements. [illegible]

NOTES ON MINIMUM REQUIREMENTS FOR SCHOOL STAGES

Provide a proscenium arch and make stage house the whole width of the hall or wider: a fore-stage of at least 6 ft. is essential. Minimum dimensions: 6 ft. fore-stage, 16 ft. behind the proscenium arch, minimum proscenium opening 25 ft. by 16 ft. Then fore-stage provides a rostrum for ordinary school purposes—lectures, prayers, etc.; it also provides good acoustics for music in front of proscenium arch. There must be steps up to fore-stage, and if doors on to fore-stage are provided it will be found that Shakespeare's ordinary scene sequences can be much more easily done. Logically the fore-stage needs the two pageant doors.

The height of a level stage above a level floor ought to be 3 ft. 10 in. Also it is important to make the floor of soft pine, and solid so as not to creak: if of hardwood, then sets cannot be nailed into it. The disadvantages of a sloped floor outweigh the advantages for amateur stages.

Rear wall of stage to be hard plastered and distempered neutral grey or light cream, thus giving a background suitable for lighting and also useful for acoustics. This background can be made into a rudimentary cyclorama by curving the ends on plan: but the illusion of space is perfectly given by the plain surface: it need not be curved. No windows, doors or radiators must be placed on this rear wall. This is important. But then some access must be provided behind the back wall from one side of the stage to the other.

A stage workshop or some adjacent room which can be used as such is highly desirable. Theatricals in the school ought to envisage the designing and painting of decorative sets. The amateur artist, carpenter and electrician will all want to contribute, and some real training in taste can be got by that means.

The upper portion of the stage ought to go up as high

cyclorama—a back wall painted white—immediately gives opportunities: for instance in Mr. Mauger's new St. Albans Secondary School hall the cyclorama was used at once, and an effective 'alchemist's cave' achieved by throwing the shadow of a retort and condenser from the chemistry laboratory straight upon the cyclorama from a floor light, and hanging an alligator from the grid above. With simple cyclorama curtains on tracks and forestage, as outlined in these notes, together with minimum lighting, it is possible for instance to do any of Shakespeare's plays.

as possible into the hall roof. Beams able to take curtain rods and eyes for flying scenery are wanted. The simplest equipment is that shown on the stage plan (Fig. 19), namely, a curtain track arranged to give two planes to curtains and two intermediate sets of scenery eyes.

In respect of lighting: lights in the hall to be double switched so that they can be controlled from both the hall and the stage switchboard. Plugs must be provided for current to lantern or cinema apparatus. A trough with removable top about 16 ft. long ought to be provided for taking footlights on the front of the fore-stage and also just in front of the rear wall. There ought to be a lighting batten permanently fixed 18 in. behind the proscenium curtain. Ceiling lights on the platform ought not to be suspended because they tend to get in the way of scenery. A place for the switchboard ought to be allowed on the left-hand side of the stage facing the audience. On the right-hand side of the stage along the side wall there ought to be a rail on which cleats can be fixed for ropes to pull the scenery up and down.

Some position for spotlights is very desirable; a recess in the ceiling at one bay forward of the platform or recesses in window reveals high up on side walls can be arranged for this purpose.

A tall door or some means of access for scenery to stage wings is necessary, though often omitted.

VIII

DESIGNING FOR MUSICAL TONE

AN EDUCATION in public taste is perceptible; the radio studio is no longer a padded room but a carefully designed concert room, and a leading gramophone company reports a real demand for music records giving more tone quality. This may lead to a demand for better public concert halls. Concert halls and music studios provide the more interesting and difficult problems in acoustic design.

When Nikisch stood with suspended baton, in the first concert hall in Europe, waiting for rustlings to subside, he knew that his loudest staccatos would be absolutely clear without the suspicion of a bump, that his strings in unison would have that envied 'singing tone', that brass would be free but not deafening, and that when the solo violin set bow to fiddle the exquisite instrument would steal up and down the upper register with perfectly balanced detachment. But we must not forget the requirements of choral music: a large choir sounds best under modified church conditions, and a good concert hall must provide sufficient reverberation to give fullness of tone to voices.

Briefly, a good concert hall has reverberation without echo, and has in it the right mixture of absorbing factors. We have said that, roughly speaking, reverberation ought to be 1·6 to 2 seconds by the Sabine formula with a full audience. This is an empirical figure founded on observation of good halls. A large concert hall intended for the proper hearing of choral works ought to have the longer reverberation as a minimum; smaller halls for strings and solo instruments require the shorter figure.

So far we have considered only reverberation at middle pitch. But for music the whole frequency range must be considered. Now absorbing materials vary in efficiency with pitch, and a graph showing reverberation time for a particular

hall at bass, middle and treble, would not be a straight line but would show variations of reverberation. Such a graph is called the 'reverberation characteristic' or 'frequency curve' of the room. Thinking first in practical terms: it is found that a good balance of tone as between treble, middle and bass is very desirable, and this can be tested by a solo violin, in its own register, by noting whether a player can use the weight of the bow alone for all notes or must compensate for the room acoustics. Also since the sensitivity of the ear varies with pitch, it is likely that an ideal frequency curve will have some analogies with that variation. But also since instrumental tone consists of combinations of fundamentals with overtones, it is clear that room acoustics must, by selective absorption, modify tone and can either enhance or spoil. And we find for instance in halls with too much porosity-absorption (acoustic tiles, plasters) which absorb at a high pitch that the quality called 'brightness of tone' is spoiled and instruments sound dull: or that in music studios absorption by curtains only will leave the bass untouched and 'boom' will be the result.

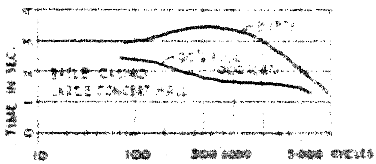


Fig. 20.—Basle Casino. Frequency Curves.

The effect of audience factor as the main absorbent is to absorb powerfully over a wide bass and middle range and generally improve tone, yet not to provide all the factors necessary for good musical requirements. The direct effect of the audience factor on reverberation is shown in some interesting tests on the Basle Casino (Fig. 20) and other Swiss concert halls.[1] It must be noted that in designing music recording studios this powerful audience factor is absent and must be compensated for by thick extensive felt on ceiling as well as walls. But other absorbents are required also. Recent research by the B.B.C.

[1] Furrer, W., *Technische Mitt.*, T. T. [illegible] 72. See also Meyer and Jordan, 'Nachhallzeiten von Konzertsälen', *Elek. Nachrichten Technik*, 1935 [illegible] 213.

has thrown light on selective absorption.[1] Broadcasting studios are designed first to suit the microphone but music studios are now reproducing concert room conditions and, throughout the B.B.C. experiments, ear tests were studied and also the reaction of the performer to the room in which he performed. It is not claimed that the tests are final, but some interesting practical results were obtained. For instance, much more emphasis must now be given to the part played by the resonance response of lining materials in a room (wood panelling, wood floors, partitions, plaster on lath ceilings) in the absorption of low tones. The preponderance of bass absorption in all halls is probably by means of this structural vibration. Wood panelling, and board and batten floor, give the most satisfactory results over a comparatively wide range: next comes plaster on wood lath, and the wide use of this for wall linings in music rooms is recommended, especially where wood linings cannot be used. Wood panelling ¾ in. thick on studs at 24 in. centres is noted as giving good results, and, if of less thickness, then 16 in. centres is recommended: it is a question of relative stiffness. On the other hand it was found that large continuous areas of plaster on metal lath may respond at a particular pitch and cause boom at that pitch. Therefore the natural decay period, or duration of response, at a particular pitch of a large resonant lining may influence the reverberation time, and therefore the frequency curve at that pitch. It was found that risk is reduced if such linings are made in separate smaller panels. Experimental work here is not complete but shows this tendency.

From these and other empirical results we can roughly generalize as follows. We have for bass absorption wood linings, or plaster on wood lath: for the middle range, audience or its equivalent in thick felts, mattressing, or upholstery: and we can add for upper middle notes curtains in light folds. But we must note that the very high tones or 'tops' do not need deliberate absorption to the same

[1] McLaren, J., 'Acoustical Design of Broadcasting Studios', *World Radio*, May 6: July 15: November 4: November 25, 1938: January 6: January 20, 1939. These are summarized for architects by the writer in *R.I.B.A. Journal* March 20, 1939.

extent because any porosity of surface or accumulation of dust on rough plaster or on reliefs will absorb 'tops' and 'tops' are needed to give brightness of tone. Also there is considerable absorption by the air of sounds above 2000 cycles.[1] Also tops are needed to give *definition* to musical notes in recording, to give 'transients' and sounds of consonants. So far from absorbing in the upper register it is well to provide a good area of glossy surface such as polished wood panelling to increase reflection in that region. Fig 20*a* illustrates how polishing a cork floor reduces absorption and therefore increases reflection at the top of the scale.

Therefore the right frequency curve must depend on providing the right mixture of materials and such a mixture

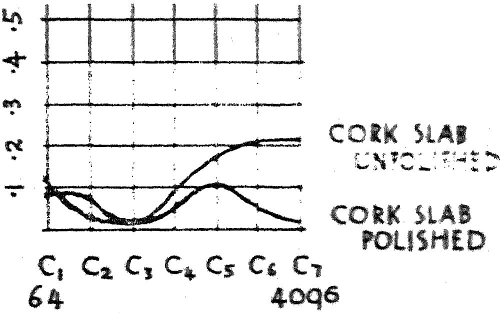


***Fig. 20a.*—Reduction of Absorption of Cork Floor** [illegible] **when polished.**

was very roughly provided by the old concert halls where polished wood, upholstery, drapery and stucco on wood lath were the common materials. And in this connection should be noted the German tradition of polishing the orchestra floor in concert rooms.

Is there an 'optimum frequency curve' applicable to music rooms generally? The Russian scientist S. Lifshitz gave an optimum on theoretical grounds, having a level portion between frequencies 600 and 2000 cycles, with a steep rise from that level towards the bass and again towards the higher frequencies.[2] Now the general object of the bass

[1] Knudsen, *Jour. Acous. Soc. of America*, July 1931, p. 126.

[2] Lifshitz, S., 'Apparent Duration of [illegible] Optimum Reverberation', *Jour.* [illegible]

rise is to compensate for lack of ear sensitivity in the lower frequencies, and of that in the higher frequencies to give brilliance to instruments by reflecting 'tops' and to give articulation to consonants. But the steep inclines given by Lifshitz are scarcely possible with ordinary materials. Knudsen has discussed a frequency curve such that all frequency components shall become inaudible at the same instant.[1] The practical difficulty is to get lining materials sufficiently glossy to reflect tops and give the high frequency rise. W. A. MacNair, the telephonist, has given a practical curve based on ear sensitivity. And this curve when reviewed in the light of experimental results in studios on actual materials, has been used as a standard by the National Broadcasting Company of America in music studio design.[2] The frequency curve for a large N.B.C. studio of 320,000 cu. ft. is given in Fig. 21, with the MacNair optimum shown dotted, a fairly close approximation of practice with theory. The Lifshitz curve is shown in the same diagram.

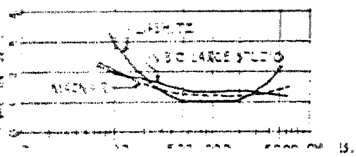


Fig. 21.—Frequency Curve.

But the method of attack preferred by Dr. Alex. Wood and the writer is to consider the frequency curves recorded by test in good concert halls. In all some ten examples are at present available. There is generally found a character of smoothness, that is to say, an absence of marked maxima and minima: there is a gradual rather than a steep bass slope and a tendency to fall in the upper register above 3000 cycles. Only in the Scala at Milan, the Philharmonie and Singakademie in Berlin and in the smaller studios of the N.B.C. in America is there recorded the desirable rise in the upper register, and it is very slight. More tests in good halls are needed. With the evidence available at present we may generalize roughly as follows. Between the frequencies 500 and 4000 cycles, within which limits the

[1] Knudsen, *Architectural Acoustics*, 1932, p. 406. See also Engl. *J. Raum und Bauakustik*, 1939, p. 237.

[2] MacNair, W. A., 'Optimum Reverb. Time for Auditoriums', *Jour. Acous. Soc. Amer.*, January 1930, p. 242; and Norris and Nixon, 'N.B.C. Studio Design', *ibid.*, October 1936, p. 81.

loudness sensation of the ear does not vary much with pitch at the usual loudness level, the curve should be level, with a *gradual* slope towards the bass, and above 4000 cycles an attempt at the slight rise.

The rise in the bass should probably be rather more for the case of larger halls and recording studios, and rather less, or even level, for smaller concert rooms, where there is danger of box resonance at low tones. A comparison between a curve for a large hall—the Scala at Milan more resembling MacNair's curve—and that for a small hall—Glyndebourne—is shown in Fig. 22. A generalized curve is shown in Fig. 23 at a reverberation level of 2 seconds suitable for large concert halls. The B.B.C. does not object to a slight fall above 4000 cycles. It should be noted that for the microphone Glyndebourne has excessive bass absorption; it needs some bass slope on the frequency curve.

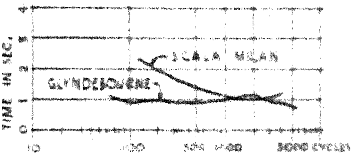


Fig. 22.—Frequency Curves.

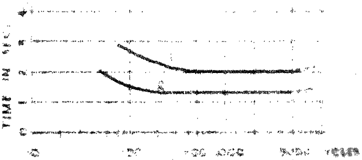


Fig. 23.—Frequency Curves generalized from existing Halls.

To sum up, therefore, we require a large wood panel area; and also remaining wall areas of plaster on wood lath on studs. These areas ought to be divided into large sections able to vibrate separately. We require also appropriate areas of the other [illegible] mentioned above. And calculations must be made at four or five frequencies in order to find the points on the frequency curve. A table of absorbents at varying pitch is given overleaf for this purpose.

DISTRIBUTED ABSORBENTS

New studies in acoustics stress the importance therefore of qualitative reverberation in designing for music. In addition there is a clear demand for a longer reverberation

VARIATION OF ABSORPTION WITH PITCH

Material.	C_1 64	C_2 100–128	C_3 250–256	C_4 500–512	C_5 1000–1024	C_6 2000–2048	C_7 4000–4096	Authority.
Brick: unpainted, 18 in. in cement	·021	·024	·025	·032	·042	·05	·07	W. C. Sabine.
Brick: painted [illegible] 18 in. in cement	·011	·012	·014	·017	·02	·023	·025	W. C. Sabine.
Gypsum plaster on tile partition [illegible]	·012	·013	·015	·02	·028	·04	·05	W. C. Sabine.
Lime plaster on wood lath: smooth finish		·024	·027	·03	·037	·019	·034	P. E. Sabine.
Gypsum plaster on wood lath: 2 coats		·016	·032	·039	·05	·03	·028	P. E. Sabine.
Gypsum plaster on metal lath: 2 coats		·02	·026	·04	·06	·058	·028	P. E. Sabine.
[illegible]	·064	·098	·112	·104	·081	·082	·113	W. C. Sabine.
Floor: wood block, [illegible]		·05	·03	·06	·09	·1	·22	B. R. S.
Carpet: thick pile		·09	·08	·21	·26	·27	·37	B. R. S.
[illegible]		·05	·12	·35	·45	·38	·36	P. E. Sabine.
[illegible]		·04	·07	·13	·22	·32	·35	P. E. Sabine.
[illegible]		·07	·31	·49	·81	·66	·54	P. E. Sabine.
[illegible]		·22	·42	·74	·77	·69	·44	B. R. S.
[illegible]		·46	·61	·82	·82	·64	·60	P. E. Sabine.
[illegible] asbestos not [illegible]		[illegible]	[illegible]	[illegible]	[illegible]			N. P. L.
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		N. P. L.
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		American Bureau of Standards.
[illegible] per [illegible]			[illegible]	[illegible]	[illegible]	[illegible]		Ditto.
[illegible] per [illegible]			[illegible]	[illegible]	0·5	0·5		Ditto.

time which shall act as a background but not interfere with definition. The ' singing tone ' imparted to violins in a few good halls is probably connected with a harmless reverberation of this kind : and ' fullness ' of tone for choral music cannot be had without a perceptible reverberation time. Now it is difficult to get reverberation without getting echo also in halls of the megaphone and fan-shape type, because all return reflections tend to find their way back to areas of concentration (for reasons analysed above, p. 82), and also because, in that type of plan, maximum sound is directed immediately upon maximum absorbing area. This is illustrated in many of the new concert halls ; tone tends to be strong and articulate : but in order, in large halls to prevent the danger of front seat echo, absorption has to be introduced in large quantities, and as a consequence reverberation is too short. It means that the megaphone type will not easily give the kind of reverberation (depending on inter-reflection) desirable for music and is not really susceptible to analysis by the Sabine formula. This points to an advantage, for music, in the older type of oblong hall.

But it is not enough to treat the old type of plan in the old haphazard method. *The aim is now to distribute a partial absorption over the main bounding surfaces, so as to give diffused inter-reflection from opposite pairs of parallel walls and hence the desirable type of reverberation* (see Fig. 23*a*).

But ' harmless ' or ' random ' reverberation is not enough of itself. There must be enough first-reflection sound to give definition by just drowning out the reverberation and making sure it is a background only : and for this purpose a good area of useful reflectors is required near the platform. Also it is found that if the high tones are well reflected, articulation is improved, and primary sounds more easily stand out against background reverberation. This again points to the need for hard glossy areas able to reflect ' tops '. If ' tops ' are active then consonants in singing can be well heard and likewise the S sounds in speech.

Another factor also enters into reverberation design. It applies in practice specially to studios and small halls. Reverberation in rectangular rooms really consists of three sets of inter-reflections set up between the three pairs of parallel opposite surfaces. It is important that these three

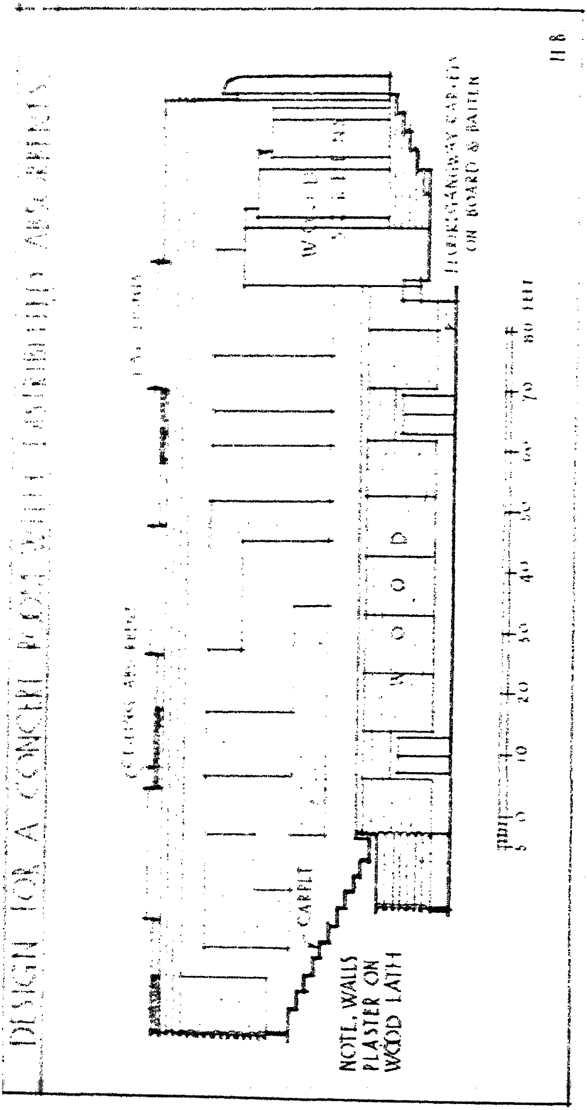
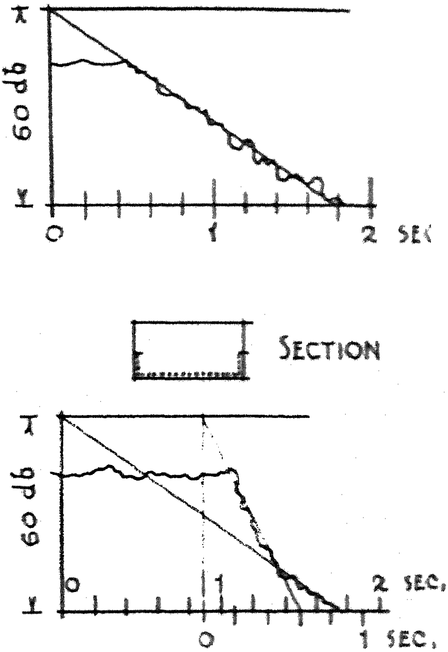


Fig. 28*a*.—Non-symmetrical Distribution of Absorbents.

reverberation times should be roughly of equal length and blend into one smooth tone. An extreme case of the opposite is found in 'flutter echo', which is the repetition of wave pulses distinctly heard between a single pair of opposite hard surfaces, and lasting for a measurable reverberation



By permission of Messrs. Philips.

Fig. 23b.—**Van Urk's Graphs showing Single and Composite Reverberation.**

time. In flutter echo the very short intervals of time between pulses are not filled in by any equally loud inter-reflection between a second or third set of reflectors, and flutter echo is heard at its best in railway arches where opposite [illegible] are of course 100 per cent. absorbing. It is also found quite noticeably in high board rooms between shiny table top and sirapite ceiling. But in rectangular music rooms it is possible

to get two reverberations of unequal length *if the sound-absorption is located on one area of the room only.* Then if a decay graph of the reverberation be taken on an instrument, a curve having two slopes indicating two reverberation times, can often be seen. This was pointed out by Van Urk,[1] and his graphs for a studio without, and with, absorption in the lower part only, is illustrated in Fig. 23*b*. The two slopes denoting two separate reverberation times can be clearly seen in the lower graph. This non-homogeneous reverberation is bad for recording studios and for concert halls, and can be avoided by the non-symmetrical distribution of absorbing materials over the whole surface area as in Fig. 23*a* above. This applies also to the floor and ceiling opposites in studios where there is no regular audience: floor rugs and, in the ceiling, some panels of absorbent are desirable.

It is also possible to increase random reverberation by the method of diffusion (see above, pp. 79 and 83). The available evidence points to the fact that while diffusion can be of great use in concert halls to distribute loudness and prevent echoes, yet if it is used to excess in music studios and small halls, as, for instance, by entirely corrugating all wall surfaces, the sound is too much randomized and a rather woolly characterless effect is produced.

LOUDNESS IN MUSIC

The question of loudness has a bearing on practical design. The success of Glyndebourne, to take one example only, was contributed to by the sense of *potential* loudness, or reserve power in the hall: it communicates an excitement. On potential loudness depends the effectiveness of the *crescendo*, which if wide in range can impart the stereoscopic or three-dimensional quality to orchestral music—the property of the good concert hall, and necessarily lacking in reproduced music. Conversely, a hall in which tone sounds 'dead', or the source remote, will not convey this quality and can seriously disappoint players and listeners. The ordinary mezzo-forte level of orchestral or piano music appears to be about 30 db. above threshold at 128 cycles, rising to about

[1] In 'Auditorium Acoustics and Reverberation', *Philips' Technical Review*, March 1938, p. 65.

70 db. at [illegible] cycles and falling to 30 db. again at [illegible] cycles.[1] This curve (see Knudsen's Fig. 71) gives also an idea of the distribution of energy over the scale. Music to be enjoyable ought not to fall far below it: when, for instance, the Lener quartette performed in Queen's Hall the loss of musical experience was marked. Clearly there must be a proportion between strength of source and size of hall. Watson gives a standard as follows: an instrument at mezzo-forte generates roughly 100 microwatts of energy: the total energy of an orchestra in microwatts ought to vary as the ⅔-power of the volume of the hall in feet units, or very roughly as the floor area. This would mean that a hall of [illegible] cu. ft. would require an orchestra giving 9400 microwatts or 94 instruments, and the Albert Hall, of volume [illegible] cu. ft., would require an orchestra of 200 instruments. For very large halls the standard does not hold. In practice the longer reverberation found in large halls gives a 'fullness' of tone which compensates, and in my view is artistically of great importance. Again, since reverberation varies inversely as absorption a useful ratio—again very rough—can be given by comparing the number of instruments to the total of units of absorption. This is given by Jeans as one instrument per 200 units.[2] This ratio is useful for music studios where volume tends to be small and absorption large. Other factors in the production of loudness are useful reflectors round platform, and the presence of wood. By introducing both these factors in the Albert Hall recently a [illegible] improvement was effected and the *crescendo* was remarkable: the hall by this means was made serviceable for medium-sized orchestras. A large proportion of the wood was varnished, thus increasing 'tops', and giving 'brightness'.[3] This was the more necessary because of the absorption of high tones by the air in so large a hall,[4] and hence

[1] Knudsen, V. O., *Architectural Acoustics*, 1932, pp. 114 and [illegible]. He is discussing Bell Telephone Lab. results—see Sivian Dunn and White, 'Absolute Amplitudes and Spectra of Certain Musical Instruments and Orchestras,' *Jl. Acous. Soc. Amer.*, 2, 330, 1931.

[2] Jeans, *Science and Music*, 1937, p. 211.

[3] For details of the Albert Hall treatment, see *R.I.B.A. Journal* for August 1941.

[4] For a study of this subject, see Knudsen, 'Effect of Humidity on Absorption of Sound in a Room and Determination of [illegible] of Absorption of Sound in Air', *Jl. Acous. Soc. Amer.*, [illegible]

the tendency to a lack of *definition* in remote seats. A dis advantage of the varnished resonators was that tone near at hand was too bright, almost harsh. There is also the problem of the solo instrument in concerto music. Knudsen says 'the difference between a single instrument as may be used in solo work and 100 instruments as in a symphony orchestra is a difference of not more than 20 db., and usually is much less because a soloist always attempts to generate an adequate amount of energy for the room in which he is performing, and on an average his power output is in excess of 100 microwatts.'[1] But solo instruments vary considerably. The grand piano, a powerful percussion instrument, developed for loudness, can hold its own superbly against a large orchestra, but the violin—still in its eighteenth-century state—is less loud and a violin concerto is less adapted to the weight of modern orchestras. For this, and other reasons, the method, tested successfully in the Albert Hall, of placing a hardwood floor reflector just in front of the platform is of considerable use. The dimensions of this in the Albert Hall were 10 ft. by 30 ft. Since 'cellos also lack loudness, Sir Henry Wood's method of bringing his 'cellos forward to the right of the conductor, in the position usually occupied by the second violins, is an advantage.

When concerts are given in *theatres* loudness problems often arise, owing to the short reverberation, and owing to the proscenium, which acts as a serious baffle. The mode of attack is to build out a fore-stage for strings and keep the brass behind the proscenium. For the same reason halls used for concerts ought not to combine a proscenium, and this is specially important for choral music.

In the above remarks certain terms have been used in respect of musical tone which can now be roughly defined as follows: '*Fullness*' *of tone* means full-pitch character—a singing quality—and is associated with a marked reverberation: it is best illustrated by a choir in modified church conditions, but applies also to strings. In my opinion it is the most valuable of tone qualities. '*Strength*' *of tone* is the achievement of adequate loudness irrespective of reverberation, and is tested by the effectiveness of the crescendo in orchestral music. '*Brightness*' *of tone* is a quality of

[1] Knudsen, *Architectural Acoustics*, p. 404.

animation and definition, is due to an emphasis of overtones, and is associated with the presence of wood and of polished surfaces. '*Deadness*' is a lack of tone experience due to over-absorption in a hall, or of absorption at high pitch with consequent reduction of characteristic overtones, or due to a simple lack of loudness as though the source was too far distant.

IX

CONCERT HALL PLANNING IN DETAIL

WE MAY summarize briefly then the result of new studies on concert hall design:

The oblong plan is preferable to the fan or megaphone.

A moderate extent of splayed surface round platform is desirable, and this can with advantage be slightly convex. A good concert hall platform is not compatible with a proscenium arch.

The rear wall behind audience must not be curved and must take the main absorption; but remainder of absorbents ought to be distributed non-symmetrically on side walls and ceiling, including strips on front side walls.

The hall must contain a large area of wood panelling which is improved by polishing, and plain wall surfaces ought to be in plaster on wood lath. A strip of hardwood floor polished and uncovered by seats is desirable in front of platform.

The reverberation times when worked out for treble, middle and bass ought to give a satisfactory frequency curve for the general musical purposes, as discussed above.

SOME CONCERT HALLS COMPARED

The best tradition of concert hall design in Europe centres upon the great hall of the Gewandhaus at Leipzig (Fig. 24) by Gropius and Schmieden. The hall has a flat ceiling with coves, and coved angles on plan: long echoes from rear wall are reduced by grilles and draped boxes. There are no carpets. Floor and platform, and likewise some 5000 sq. ft. of wood panelling, are kept rubbed. Seats are partly upholstered, and absorbing material in the form of fabric is distributed in alternate panels along side walls. The tone has real 'fullness', strings are 'bright' and rapid staccato

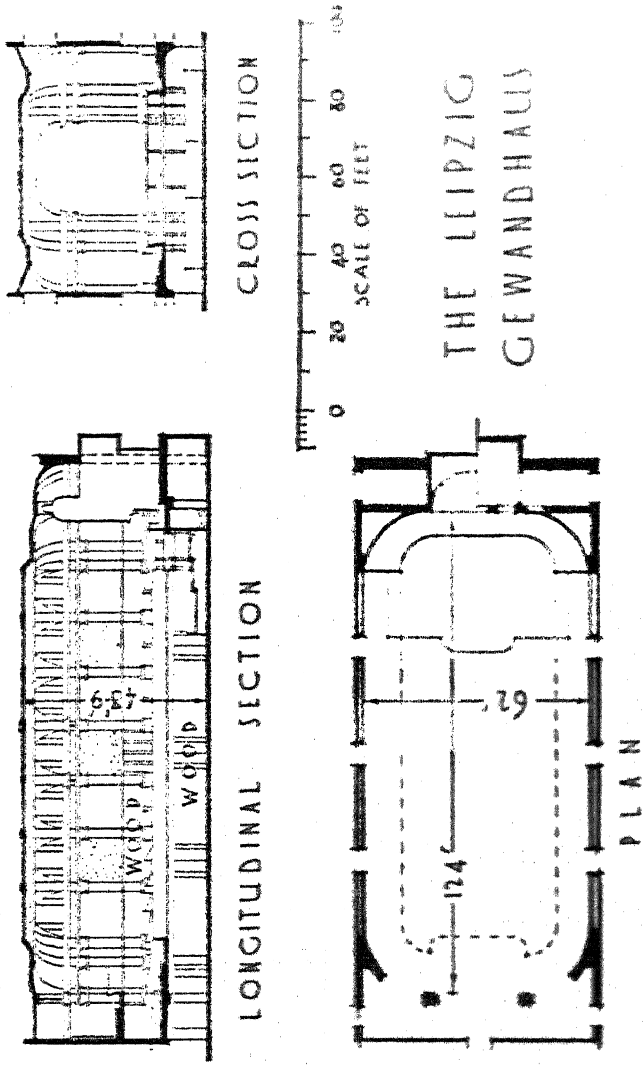


Fig. 24.—Leipzig. Gewandhaus Large Hall.

is possible. The cube per seat is high, namely 230 cu. ft. The reverberation appears to be not so long as calculation shows,[1] but is between 1·6 and 1·8 seconds with hall fairly full. The influence of the Gewandhaus can be traced in the Grosser Tonhalle-Saal in Zurich, and in our own Free Trade Hall, Manchester, and many other halls. Breaks and reliefs are part of the tradition.

The Queen's Hall (Fig. 25), designed by Mr. Knightly in 1890, was destroyed by enemy action on the night of May 10, 1941. It was in many ways so satisfactory for general musical purposes as to set a standard and leave a tradition. The tradition might be called that of the convex reflector. Sound from the orchestra platform was well distributed over the hall from the convex splays, as is shown on the figure. The segmental rear wall, however, behind audience had a radius of 50 ft., struck from about the centre of the plan, and caused unequal concentration of return sound at ground floor level but not sufficient to cause an echo: but this feature ought not to be imitated. Reverberation was too short to give 'fullness' of tone, and this was noticeable in choral music: a larger cube per seat would have been preferable. But orchestral music was saved from deadness by the large amount of resonant material, namely 6000 sq. ft. of wood, and the plaster surfaces—a fibrous plaster on wood. The difference in reverberation (and therefore in fullness of tone) as between Gewandhaus and Queen's Hall corresponds roughly to the difference in the cube per seat of the two: the Gewandhaus was 230, the Queen's Hall was 208 cu. ft. per seat.

It should be noted that the London Building Act, by severely restricting the use of wood panelling with air space behind, makes the designing of a good concert hall difficult: the best buildings for music in London—Queen's Hall and Covent Garden Opera House—were both built before these restrictions were imposed.

The barrel vault had proved dangerous before 1890 (date of Queen's Hall), and we find that about that date a theory was advanced that a ceiling something between the flat and the barrel, namely the segmental, would strike the right mean

[1] See Meyer and Cremer, *Zeitschrift für Technische Physik*, 1933, p. 500.

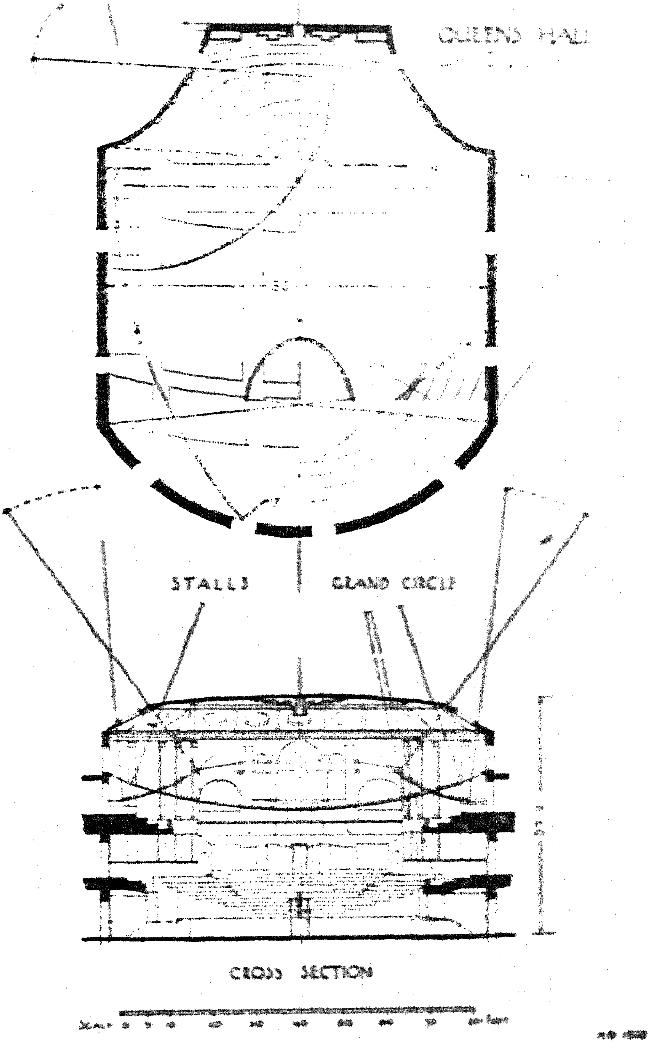


Fig. 25.—Queen's Hall.

between the two. The segmental ceiling type was the result. The great hall at the Royal College of Music is an example. But we have seen (p. 84) that the segmental ceiling concentrates sound acutely, and since its adoption it has in fact caused more serious complaints than any other form. This is noted as a development occurring, and causing

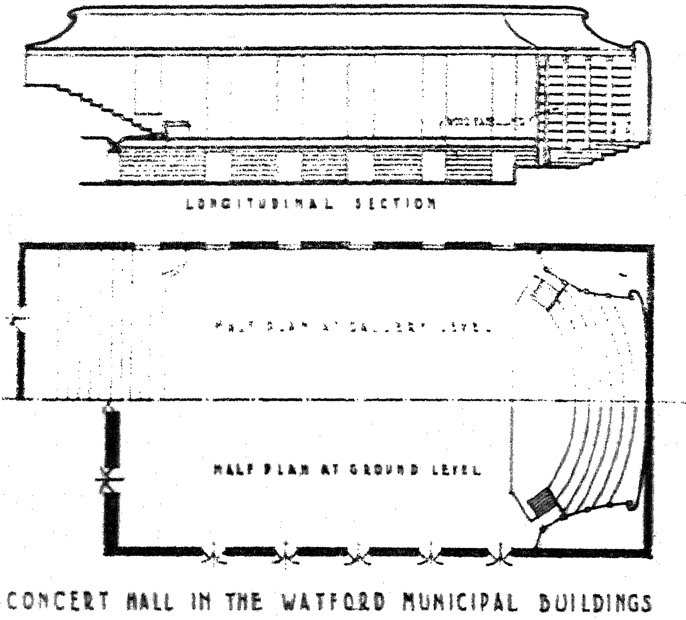


Fig. 26.—Watford Town Hall. Architect: C. C. Voysey.

trouble, owing to insufficient knowledge. The method of getting the right reverberation is, of course, to adjust total volume to total absorption as already described, and provide a flat ceiling that will distribute sound and not cause echoes.

The Colston Hall, Bristol, by Jones and Cummings, was quoted as giving a standard of good tone in *Planning for Good Acoustics*, 1931: the hall had then a calculated reverberation of over 2 seconds with 1760 seats occupied,

had 3000 sq. ft. of resonant area, and gave a fine full tone for instruments and voices. It has since had the seating increased with a [illegible] reduction in reverberation and consequent serious complaints from the musical societies of Bristol. Where a fine choral tradition exists in a city it should be recognized as an artistic heritage and carefully carried on in the concert halls of the city.

The new town hall at Watford, by Mr. C. C. Voysey, is a good modern example in which the convex splay is used

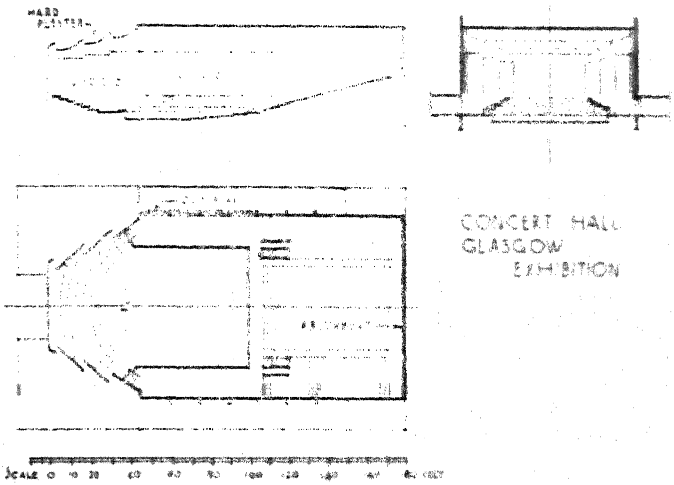


Fig. 27.—Glasgow Exhibition. Concert Hall. Architects: Sir John Burnet, Tait and Lorne.

with advantage (Fig. 26). But if halls designed deliberately for music have their platforms rigged with curtains and back-cloths the tone of instruments will be ruined.

The concert hall built by Sir John Burnet, Tait and Lorne for the Glasgow Exhibition (Fig. 27) illustrates the use of overhead convex splays, side screens in wood, and a floor made partly flat and partly ramped. Here a large area of wood with glossy finish gave brightness of tone and compensated for a shortness of reverberation made necessary for general purposes.

Where a good organ is to form part of a concert hall then it requires a light thin grille, not a heavy fibrous plaster grille, to screen it. An organ of the cinema type can be placed behind vanes but requires large openings between them: an example is shown on the platform of the large hall at Wolverhampton (Fig. 28). Care was taken over the acoustics of the Wolverhampton halls by the architects, Messrs. Lyons & Israel, and it is reported upon favourably by conductors. For organs see also p. 130.

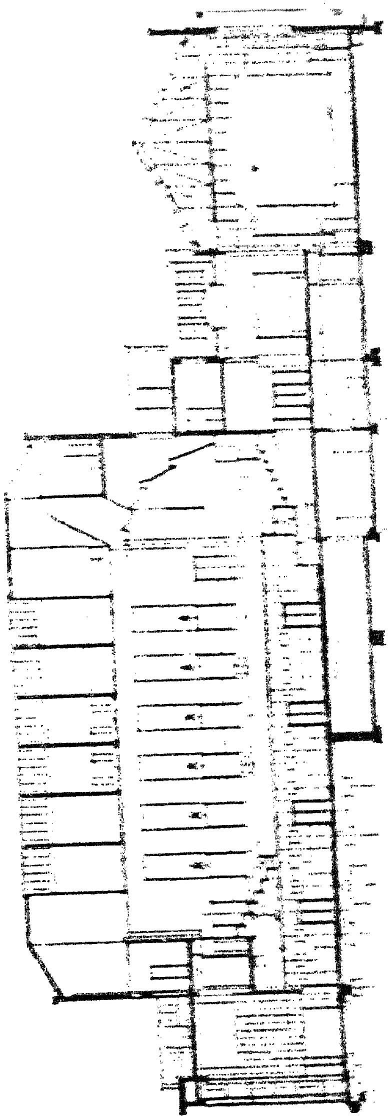
CONCERT HALL PLATFORMS [1]

As a guide to the number and variety of instruments used, the table showing the composition of the B.B.C. Orchestras is given here.

The B.B.C. Orchestras. The smaller orchestras into which the full B.B.C. Orchestra can be divided—each complete in itself, and suited, in numbers and balance, to the types of music entrusted to it, are:

Instruments.	A.	B.	C.	D.	E.
First Violins .	20	14	6	12	8
Second Violins	16	12	4	10	6
Violas . .	14	10	4	8	6
'Cellos . .	12	8	4	7	5
Double Basses	10	7	3	6	4
Flutes . .	5	3	2	3	2
Oboes . .	5	3	2	3	2
Clarinets .	5	3	2	3	2
Bassoons .	5	3	2	3	2
Horns . .	8	4	4	4	4
Trumpets .	5	3	2	3	2
Trombones .	6	3	3	3	3
Tuba . .	1	1	—	1	—
Timpani. .	2	1	1	1	1
Percussion .	3	3	—	2	1
Harps . .	2	1	1	1	1
	119	79	40	70	49
		119		119	

[1] The following notes are republished with permission from the *R.I.B.A. Journal* for May 23, 1936.



LONGITUDINAL SECTION

Fig. 38.—Wolverhampton Municipal Halls. Architects: Messrs. Lyons & Israel.

The B.B.C. Orchestra A is abnormally large: few provincial platforms would have to be designed for an orchestra of more than about eighty players. Even the big world-famous orchestras when they tour seldom take more than about 110 players. These figures represent the standard B.B.C. combinations; frequently provision has to be made on the platform for the addition to the number of instruments in particular sections. In much modern music there may be up to five each of the wood-winds with correspondingly heavy brass.

The *Conductor* must be where he can obtain a good clear view of every player and where he can be seen by all. This inevitably means that except in the case of small chamber orchestras he must be raised above the level of the flat. Since conductors' tastes vary, it is inadvisable to provide a fixed rostrum which cannot easily be adjusted in height and position. Some conductors, for instance, prefer a comparatively low stand, with no railing at all, back, sides or front, and to have an ordinary movable music stand. Some take their own rostra with them on tour, making it necessary for the hall rostrum to be easily removable. The architect should, however, assure that no feature in his design ever makes it necessary to place any of the players behind the conductor, but no hard-and-fast rules can be made. Most continental conductors in concertos prefer to stand *between* the pianoforte and the orchestra, where they can hear better and not have to peer over the pianoforte lid to see the centrally placed players. Ideally it should be possible for the outside row of the string players to be inside the 180° line. The floor of the conductor's stand will vary in height above the 'flat' from 1 ft. 3 in. to 2 ft. 6 in. The rail should be as simple as possible, nothing more than four uprights and a single top rail.

Fiddles.—Almost invariably the first fiddles are on the conductor's left. They and the players of most other instruments sit in pairs sharing a desk. The 'flat', as the level portion of the platform is called, should be large enough to take all the strings if possible. (This is a counsel of perfection.) As far as fiddles are concerned there should be room for four players side by side. Two fiddles, with chairs and a desk, will need a space about 4 ft. by 3 ft. (Fig. 29).

Generally speaking, the players are seated as close to each other as possible. Second fiddles are usually on the right, placed in the same way as the first fiddles; or on the left next to the first fiddles, in which case, unless the flat is wide, they will extend up the rise. In this case the 'cellos and violas which might otherwise be on the conductor's right are forced up the rises and into the the central part of the flat.

Violas.—The violas are generally placed on the flat in the right centre. They need the same space per player as fiddles.

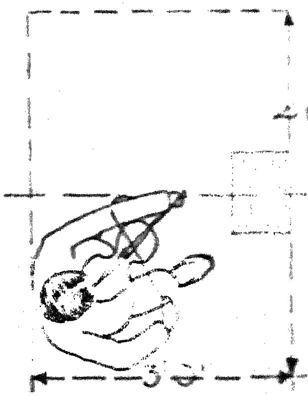


Fig. 2[illegible].—Area necessary for [illegible]

'Cellos and Basses.—The 'cellos and double basses are difficult instruments to place comfortably.[1] Serious trouble can result unless the level part of each tier is adequate to take chair, music stand and the peg of the instrument without risk of upset or disturbance of the players in the row in front. If for some reason it is impossible to provide 4 ft. 6 in. tiers, extensions should be provided which can be used to build up a tier to the necessary width. These extensions must be made to fit close and true, and to be secure against all movement. There must be no risk of a chair or music stand leg or 'cello peg slipping into the joint.

Wood-Wind.—These are usually placed centrally; the players of each type of instrument sit side by side, sharing one desk to two players. The smaller instruments need no more room than that required by a man sitting upright with a music stand in front—2 ft. by 3 ft. is generally sufficient. Bassoons need more space laterally, and should be given

[1] Author's Note.—I [illegible] Sir Henry Wood's location of the 'cellos [illegible] conductor and corresponding to the first violins [illegible] double basses come above them on the [illegible] rises. This plan enables them to be better heard.

3 ft by 3 ft. Certain players use two instruments and need space for the second instrument. Peg stands are usually supplied for the purpose.

Brass.—The smaller brass instruments need no more than sitting space with, of course, provision for the music stand. Large instruments, such as trombones or tubas, should be given more. Trombones must be given room for full extension clear of the slide.

Percussion.—These are more trouble to place satisfactorily than almost any other players. Certain composers call for an infinity of different percussion instruments, most of which need considerable clear, level space. Platform extensions must be provided. (See 'cellos and basses, above.) Percussion instruments are always placed on the highest rises in use, though it has been suggested that musically a better blending of drums and the other instruments would be obtained by placing the former at the back of the flat in the centre. One player may deal with two or more instruments, and space must be calculated accordingly. As much as 15 ft. length of tier extension may be wanted.

Tympani need a semi-circle of between $2\frac{1}{2}$ to 3 yds. in diameter.

The Organ.—The position of the organ and the organist need not be the same. It is as necessary for the organist to be in close contact with the conductor as for any other performer; consequently to have the console in a gallery, as formerly at Queen's Hall, is bad. It is possible to arrange the console on an electrically operated platform which can be lowered out of the way: if this is done the console can be placed centrally at the back of the flat. The presence of a large semi-fixed unit of equipment undoubtedly destroys some of the platform's flexibility, but it is difficult to place the console so as to satisfy every one. An alternative position might be at the side, with the organist seated so as to see the conductor without using a mirror.[1]

The Chorus.—In English provincial life choral concerts are much more important than occasional visits of large orchestras. Ample provision should be made on the platform for a chorus of not less than 250 persons, allowing space for

[1] See also 'Municipal Buildings', paper by Percy Thomas, *R.I.B.A. Journal*, 1935, p. 480, for notes on position of organ in town halls.

an orchestra of medium size as well. The members of the chorus can be seated reasonably close to each other.[1]

General Platform Details.—Some of the detail sizes have been given above. Multi-purpose halls may have all the tiers or rises removable so as to free the platform for other uses than concerts, but if this is so, adequate storage must be provided for the tier units, which are stoutly made and heavy, and cannot easily be moved far. A grand piano occupies a space 9 ft. by 5 ft. 2 in. (Fig. 30).

The Flat.—The flat should be 40 ft. to 60 ft. in width, i.e. the full platform width, and 15 ft. to 18 ft. in depth. This will take four players side by side, with passage way to spare for the conductor and soloists to pass to the centre of the platform. If space for fewer than four players abreast is given, care should be taken to see that the platform width is adequate, or it may prove impossible to fit in the fiddles. It is possible to provide a forward extension to the flat, brought out on runners from under the permanent flat. There must also be space for vocal soloists to sit well to the front of the stage, and for instrumental soloists. All soloists should, if possible, be given places where they will be able to catch the conductor's eye. A small extension of the platform forward for the conductor only is a good way of assuring that he will be able to see all the soloists without driving them back from the front of the platform.

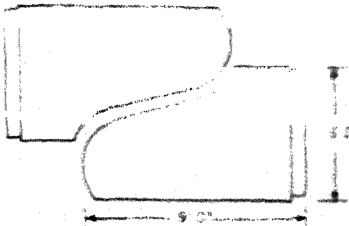


Fig. 30.—Grand Piano: Dimensions of Plan.

Rises.—Rises should be 3 ft. minimum, 4 ft. 6 in. maximum in width, above 4 ft. 6 in. the orchestra becomes unduly dispersed, and the upper ranges of instruments too far from the conductor for easy control. But it is an advantage, wherever possible, to have the lower rises capable of taking

[1] A large chorus room or musicians' common room [illegible] to choir staging is essential, likewise a soloists' room [illegible] on conductor's left.

'cellos and double basses, thus permitting maximum variations in the layout of orchestras. In planning the rises it should be borne in mind that the platforms of most halls will on occasions be used to seat part of an audience—at mass meetings, etc. The tiers must allow this.[1] The vertical dimension of the rise can vary as long as it is sufficient to assure that the players and conductor are in view of each other. It should also be remembered that the audience like to see the players. A good depth is 1 ft. 6 in.; sometimes greater depths are used, but are apt to be dangerous. The rises should curve round; the more the radius of the curve can centre on the conductor the better.

Provision for Broadcasting.—It is generally desirable to-day to make provision for broadcasting. This involves the provision of suitable accommodation, probably behind the platform, for the amplifying equipment and for the engineer and the control man to work. Contrivances must also be provided by which microphones can be slung in whatever positions the experts may choose. The control room must be acoustically isolated from the platform, so that the controller may concentrate on his instruments and listen to the broadcast by means of a loudspeaker, and not hear the original sounds. It should, however, be so situated as to provide convenient access to the platform for consultation with the conductor during rehearsal. The ideal arrangement is to have two adjacent rooms, one for the greater part of the apparatus and one for listening and operating the controls associated with the various microphones. The former room should be about 6 ft. by 10 ft. and the latter not less than 12 ft. by 10 ft. In smaller listening rooms satisfactory acoustical conditions for critical listening cannot be obtained. Full acoustical treatment of the listening room is most desirable. If two rooms cannot be obtained, use can be made of one for both purposes, provided it is not less than 15 ft. by 12 ft. in size. Less accommodation is detrimental to satisfactory broadcasting, and can only be considered as an emergency arrangement.

The microphones are slung in front of the orchestra.

[1] But for musical tone it is important *not* to upholster choir staging seats permanently. Movable chairs should be placed on the rises when needed.

Their position varies with the types of music being played and with the type of microphone used. The latest type of microphone, the ribbon, can be placed much farther from the players than older types. The architect should attempt to ascertain what the B.B.C. requirements are likely to be, whether or not broadcasting has been contemplated for the hall in question. Normally, unless the hall is a regular broadcasting centre, all that is necessary is the provision of fixings from which the microphone is slung. If frequent broadcasting is to take place, proper cables and pulleys and access boxes should be provided.

X

ACOUSTICS OF CHURCHES

CHURCHES COME last in this book, but they are of first importance: because of their purpose, and because civilization still rests upon the golden chain of goodwill among men.[1] I have said that our problem in church design to-day is to add an auditorium to a shrine. The shrine, the element of worship, must be preserved at all costs. Its re-assertion and re-embodiment in fine buildings was the achievement of our grandparents in the Gothic Revival and it was a real achievement: it has given us Westminster Cathedral and Liverpool Cathedral—great buildings—and it re-animated church architecture. But the Gothic Revival did a disservice: it tended to destroy the acoustics of the reading and preaching voice. Thousands of old churches were scraped and emptied, their galleries, lofty pulpits, old screens and hangings removed: and as reverberation went up so good hearing went down. At the same time new churches were built with high vaults, tiled floors, ash chairs, low pulpits. The free churches followed the mode: the pulpit was moved from the centre to the side; the consequent void demanded the aesthetic of the altar and the aesthetic has been supplied. At the same time the sweeping away of the west galleries left a hard bare west wall; echoes were added to reverberation and there are hundreds of free churches in which the interpretation of the Word—the centre of the service—has never been properly heard. But the situation now is not that of the nineteenth century. To-day in our great Christless cities and housing estates a remnant of Christian people are striving to bring the gospel again into our lives. There is everywhere ignorance of Christian teaching, so that to-day every church ought to be a mission church, or include that

[1] There ought to be no such thing as pure technology; purely technical man tends to destroy himself by technical warfare.

element, just as early Christian churches included the basilica or hall, and the altar or shrine. We do not want a reaction—a futile swing of the pendulum—but an intelligent synthesis, a placing of the two side by side, and to use our art in making a relatively cheap building noble and beautiful.

One might say that the difference between the organized churches and between the buildings expressing them lies in the degree of emphasis to be given to these two elements. Roman and Anglican lay emphasis on the shrine, the Free Churches on the pulpit. The acoustics of the shrine in an extreme form give the long reverberation suitable to intoning the Mass and to polyphonic music. The acoustics of the auditorium in an extreme form give the short reverberation of the post-Reformation Scottish church with its three galleries in equal arms of the building, and consequently the small cube per seat and short reverberation, suitable to the old Presbyterian service. But neither extreme form is logical to-day. Roman and Anglican require good pulpit conditions, and the Free Churches are concerned to get good choral music. This can be expressed as the problem of finding for each the suitable compromise in reverberation. Very roughly we can say that Roman and Anglican churches of moderate size require a reverberation between 2 and 3 seconds by the Sabine formula, with a fairly full congregation, and the Free Churches about half a second less. But regard must be paid to a musical tradition if it should exist in a parish, as frequently occurs in Yorkshire towns. A west gallery is musically the best place for choir and organ—it can become a school of music as in the Lutheran church. Bach's music was largely written for, rehearsed in, and performed in the west gallery of Leipzig churches. But then the nave must not be too long, and the ceiling bay over gallery must be hard, not absorbent. Another method is to design the choir with a perceptible reverberation, and the nave more absorbent: but then the choir may not be in a position to hear lessons and sermons, and hearing is less good in respect of the altar and Eucharist service. It is wise to pick up the intelligent tradition, and some types of churches are much better than others. Buildings easily giving good acoustics are as follows: the smaller 'Basilican' or Early Christian types: the 'Dominican' or preaching

church of the later Middle Ages with continuous flat vault over nave and aisles; the Perpendicular parish church or 'hall church', with a wooden roof and without transepts; the Wren city church of the smaller variety having a flat ceiling. Also some interesting medieval special types are shown in Fig. 31.

Although it is not suggested that these types be deliberately imitated, yet, if models are sought for the sake

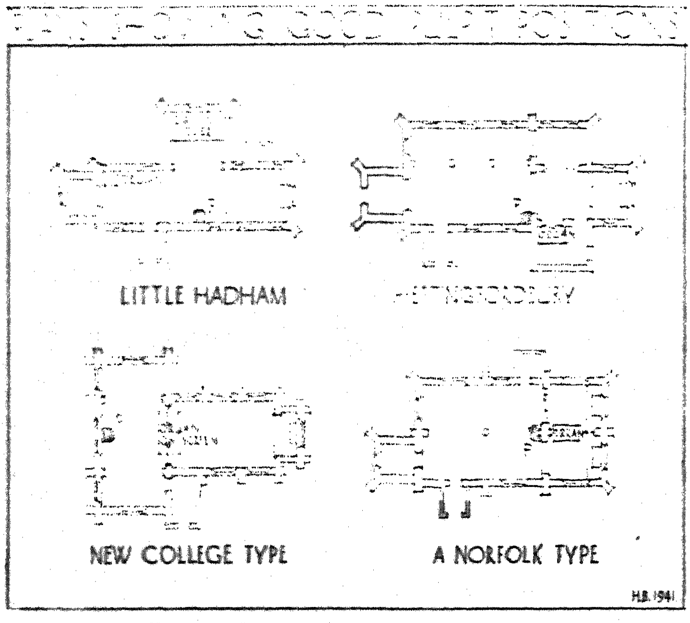


Fig. 31.—Some Medieval Auditorium Plans.

of Christian tradition and association, these types are appropriate from a practical and economic point of view just as, conversely, those involving domes, barrels, pendentives, high vaults, high 'crossing' are not appropriate. But no shape of church will guarantee good acoustics if built to a large scale with hard modern materials. A church seating six hundred is likely to require some special sound-absorbing material *unless the gallery seating is large, and the*

church generally well filled. The best positions for special absorbents are (*a*) west wall, (*b*) nave roof, (*c*) the end walls of transepts, especially if they are deep transepts. Some ordinary building materials provide greater natural sound-absorption than others. For instance, a lime plaster having a sand-faced finishing coat, not gauged with cement, is better than a hard gypsum plaster. But if the lime plaster be distempered then its slight porosity is destroyed and it loses its advantage. Sound absorption depends in such cases on porosity, therefore the fact that a plaster is rough will not of itself cause sound absorption unless it has already an open porous texture.

A timber roof generally gives better acoustic conditions than a stone vault or a stone or plaster ceiling. Yet a barrel or segmental ceiling in wood can cause trouble. A [illegible] roof is provided by the ordinary principal and purlin roof having panels of fibre board on the under side of the rafters. If these fibre boards are left undistempered, they will give some 20 or 30 per cent. sound absorption. An open queen-post roof truss also gives a good acoustic ceiling shape. If the appearance of a vault is required for artistic purposes, it can be approached by a three- or four-sided waggon ceiling, well pitched up. The straight sides avoid the dangers of the curved vault surfaces, and if necessary can be in fibre board or can take an absorbent plaster on lath.

Also since very many acoustic complaints are associated with *transepts*, a new church is better designed without them. Or if used, they ought to be as shallow as possible. Deep transepts will require sound absorbents and are therefore an unnecessary expense.

Sounding boards to pulpits are only useful in very large churches having considerable vault height. It is more profitable in small churches to spend money, not on a sounding board, but on a sound-absorbing treatment. In large churches the sounding board ought to be part of a properly designed reflector-pulpit able to project the voice to remote seats and cut off sound that would otherwise go to the ceiling and cause reverberation. Pulpits are increased in efficiency if placed so as to have a back wall. Also the higher they are the better. The stretching of wires in churches is useless.

Loudspeakers can be useful in large churches if care is

taken with their location, design, general arrangement. But where a long reverberation exists they introduce problems of their own, difficult to overcome, and which in many instances have caused failure. In the design of a large new church, therefore, a proper loudspeaker design must include special sound absorbents so that there shall not be excessive reverberation. If amplification is sought as a remedy for defects in a large and reverberant existing church, then the loudspeakers must be many and limited in loudness, rather than few and powerful. That is to say, a number of 'soft speakers', each reaching a limited area of seats, will give the best results, and acoustics are helped if a cord carpet is placed under seat areas and on gangways. Also it is well to have loudspeakers switched in groups, dissociated, upon a control board, so that a few at a time can be used. The control board must be placed where the church acoustics are experienced during service, and intelligent control is required. Finally, proper maintenance is quite as important as the initial design, and it is well to have a church officer who will give them his constant attention, and who will be at the control board during the service.

A preacher ought to speak quietly in front of the microphone and deliberately substitute the sound of the loudspeakers for his own voice.

Organs from an acoustic point of view are well placed when they are in the main cell of the church and under the same ceiling as choir and congregation. This is specially important if they are to lead congregational singing. Thus neither a deep transept nor a bay of the choir aisle are good positions. The best position, in my opinion, is a west gallery. A shallow transept formed by carrying up a bay of the nave aisle the full height of the church gives a good position suitable for a choir occupying a forward position, and is good also for leading congregational singing. A tall tribune gallery in the first bay of the choir, allowing some projection of the choir organ, can be satisfactory for a trained choir in a forward position, but often causes complaints for congregational singing. In cases where consoles are detached the instrument itself ought not to be further away than 20 or 30 ft. It is said that nine out of ten church organs are out of tune, so that for a given sum of money it is better to pro-

vide a smaller instrument and keep it in repair than a larger instrument too expensive to maintain properly.

Churches are often exposed to serious *noise risk*. In this respect a frequent cause of trouble is the west window on a noisy thoroughfare. Such windows ought not to occur in new designs, and often the best remedy to an existing church is to brick them up. If a west window is wanted for light on an unavoidably noisy site then it must be as small as possible and have ¾ in. glass in a heavy steel frame. Often noise can be prevented by [illegible] that the windows on the noisy e[illegible]

In remedying acoustic defects in existing churches it must be remembered that scaffolding is a major cost, so that it is well to combine a new acoustic treatment with a period of redecoration when scaffolding shall be in position.

Hall Churches.—In new housing estates parish church and hall are sometimes combined, and some splendid mission work is being done in buildings of this kind. Part of the church building is consecrated as shrine and divided by a movable partition or by curtains from the adjoining hall. The hall can then be made suitable acoustically for preaching, teaching and for stage plays, and the shrine left hard for choral music. A small chapel for private prayer is desirable. It is interesting that a prototype of this exists in the chapels of New College and Magdalen, Oxford. These buildings are an inverted T on plan; the vertical stroke being shrine with choir, the horizontal being originally for more secular uses as a preaching place; an organ on a screen divides the two (see Fig. 31).

The Modern Cathedral might be interpreted in the same way as ministering to secular needs as well as to sacramental in respect of a metropolitan area, exactly as in early Christian times. A tendency in this direction already exists in the extended use of the nave in many of our old cathedrals. All aspects must be related to, and dominated by, the sanctuary. Then the nave could be a theatral area for sacred plays as well as for ceremonial, and special services, and for musical festivals, such as that of 'the Three Choirs'. A smaller limb or large 'galilee' could be made more definitely an auditorium for preaching, lectures, films, the communal break-

fast. Private chapels for prayer are essential; and the whole embodied in a noble group of buildings.

In addition, the porch which is not consecrated could be opened out so as to become more the early Christian atrium or open-air auditorium inviting passers-by out of the street. In the atrium, loudspeakers on Sunday morning could give the lessons and gospels; and a well-designed loudspeaker system for all parts of the church ought to form part of the design.

INDEX

Heavy type denotes illustration or diagram

PRINTED BY
MORRISON AND GIBB LTD.
LONDON AND EDINBURGH